The Large Hadron Collider project

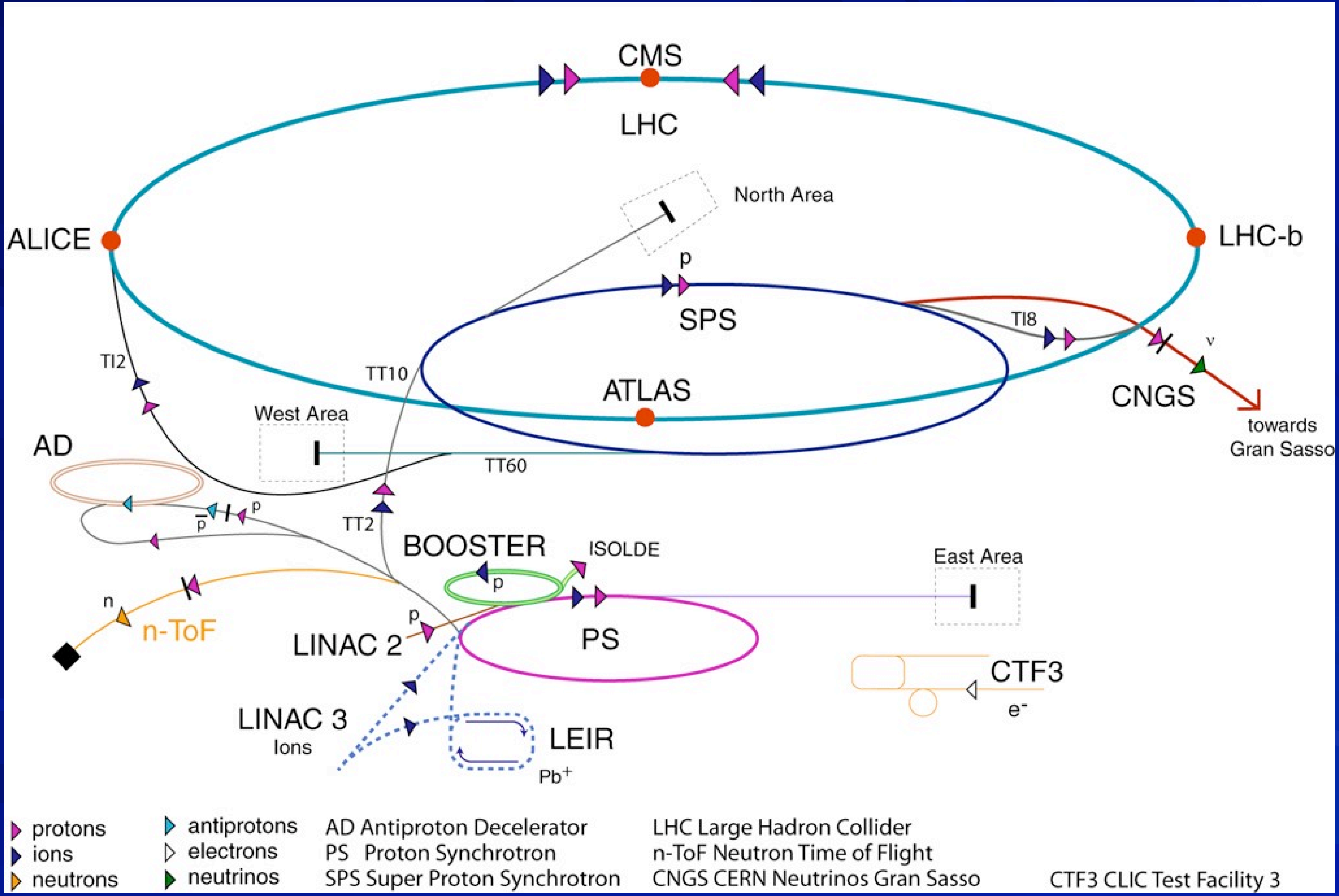
- Accelerator – collider
- Detectors
- Computing
- Physics

This presentation:

mainly status of the detectors

Jos Engelen
CERN

CERN: the World's Most Complete Accelerator Complex
(not to scale)



The Large Hadron Collider

The Large Hadron Collider: 14 TeV pp collisions at 10^{34} $cm^{-2}s^{-1}$

New energy domain (x10), new luminosity domain (x100)

Will have to cross threshold of electroweak symmetry breaking; unitarity of WW scattering requires $M_{Higgs} < 850$ GeV

Many possibilities: Standard Higgs – SUSY (many possibilities...)
-Large Extra Dimensions (quantum gravity)

-and many more results on CP violation, Quark Gluon Plasma, QCD, ..., surprises...

The LHC results will determine the future course of High Energy Physics

The LHC (Project Leader Lyndon Evans)

LHC Installation

- Main objectives:
  - terminate installation in February 2007
  - first collisions in summer 2007
- The industrial production of standard components is compatible with this objective.
- The ramping up of QRL activities and magnet installation is critical to maintain this schedule.
- Additional actions have been implemented to ensure proper QRL production and installation rates.
- The installation and interconnection of cryomagnets have started in the tunnel.

The Detectors

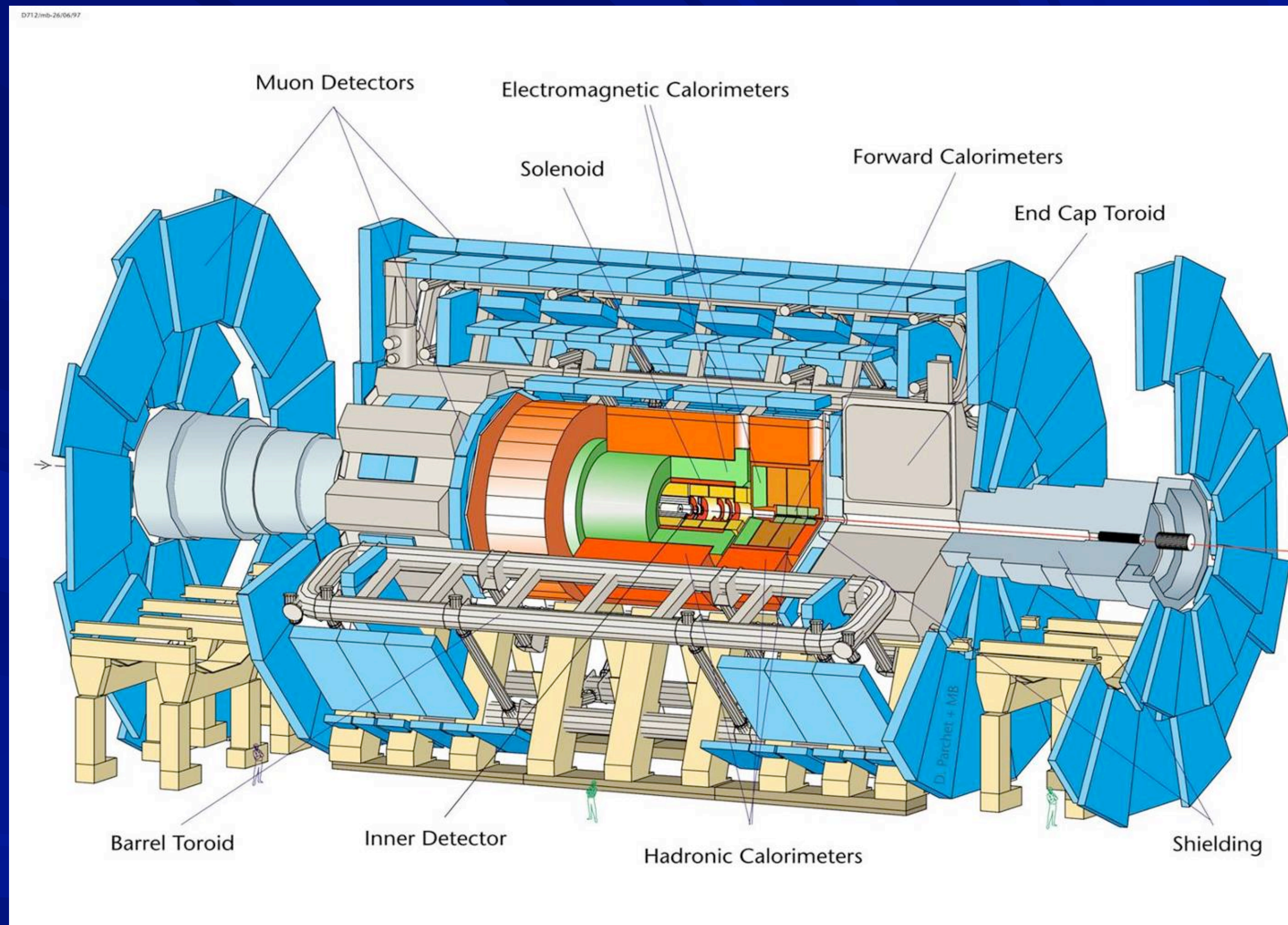
Event rate 20 - 25 per bunch crossing (every 25 ns)
--> 10^9 events / s --> 10^{11} - 10^{12} tracks /s

Very remarkable: experiments will, in this environment:

- reconstruct secondary vertices from B mesons, only mm's away from the primary vertex.
- reconstruct individual photons with sufficient energy and angular resolution for (light) Higgs detection

in addition to many more capabilities: they are 'general purpose - 4π' detectors, featuring tracking, magnetic momentum analysis, calorimetry, muon spectrometry, in an almost **hermetic** setup

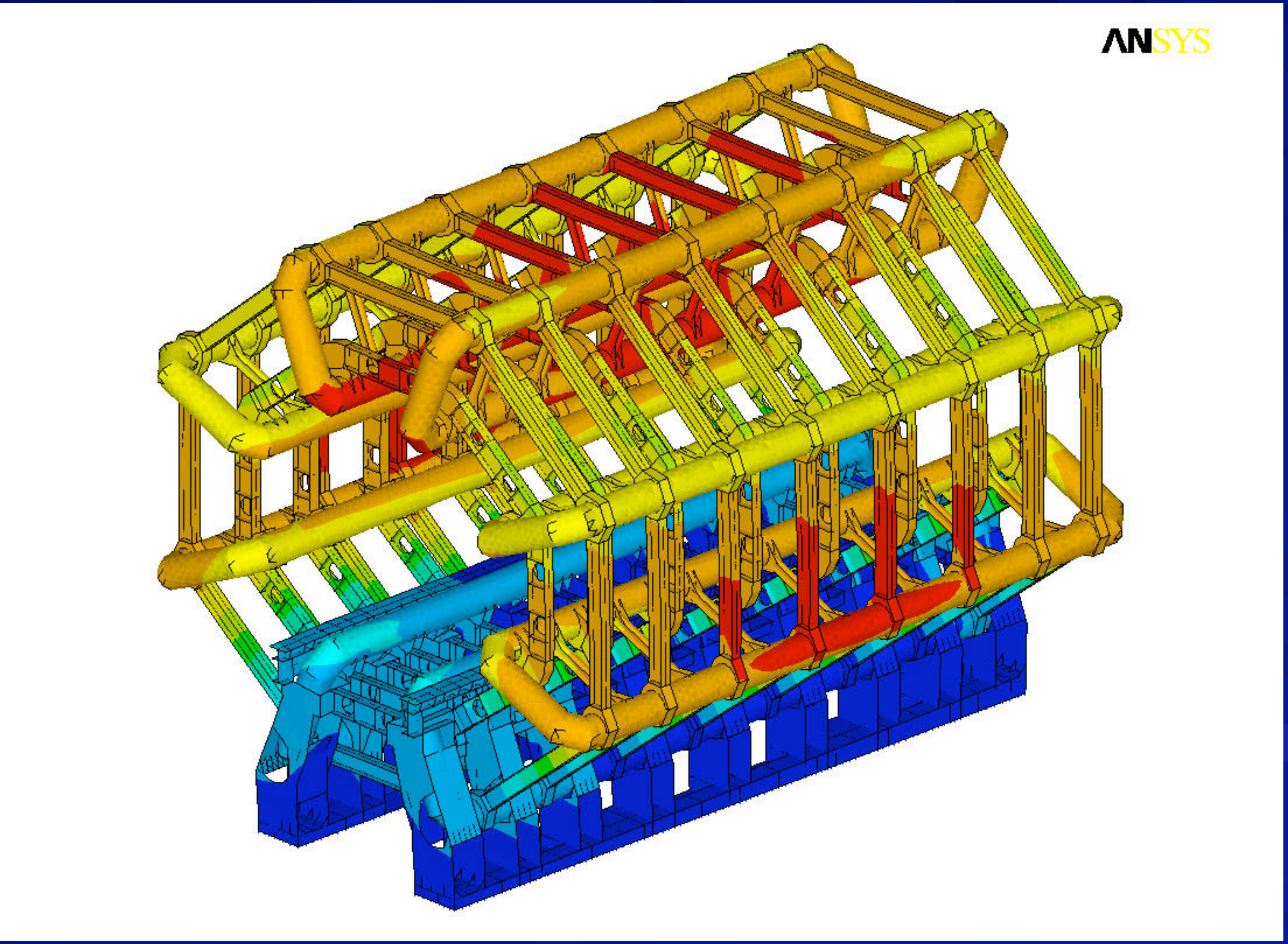
ATLAS (spokesperson Peter Jenni)



ATLAS superimposed to
the 5 floors of building 40

Diameter	***25 m***
Barrel toroid length	***26 m***
End-cap end-wall chamber span	***46 m***
Overall weight	***7000 Tons***

The Barrel Toroid

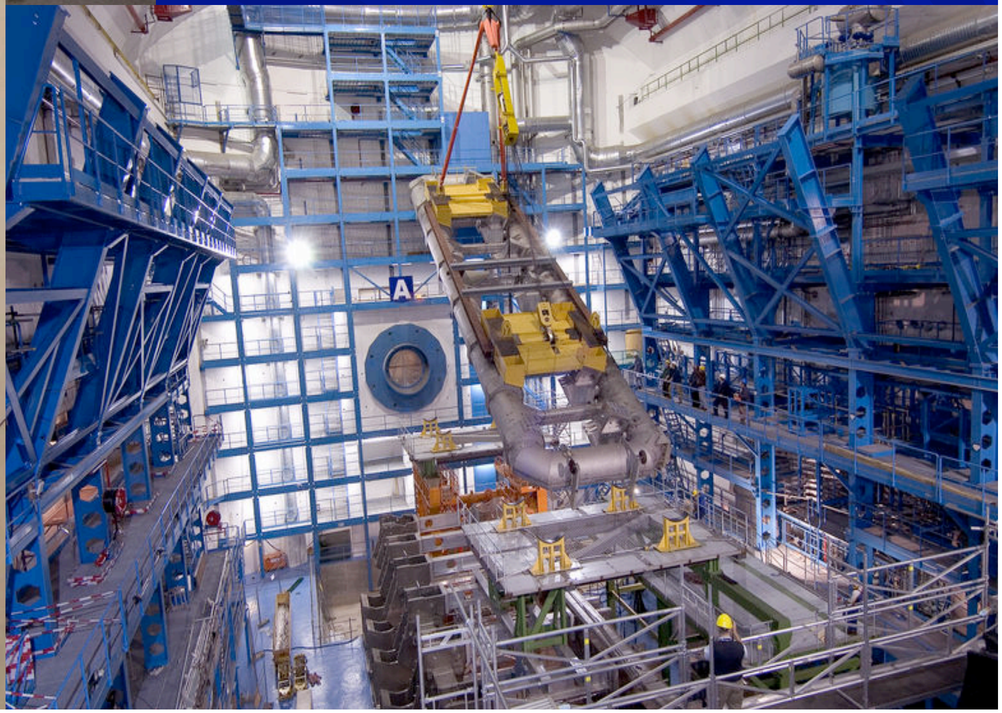


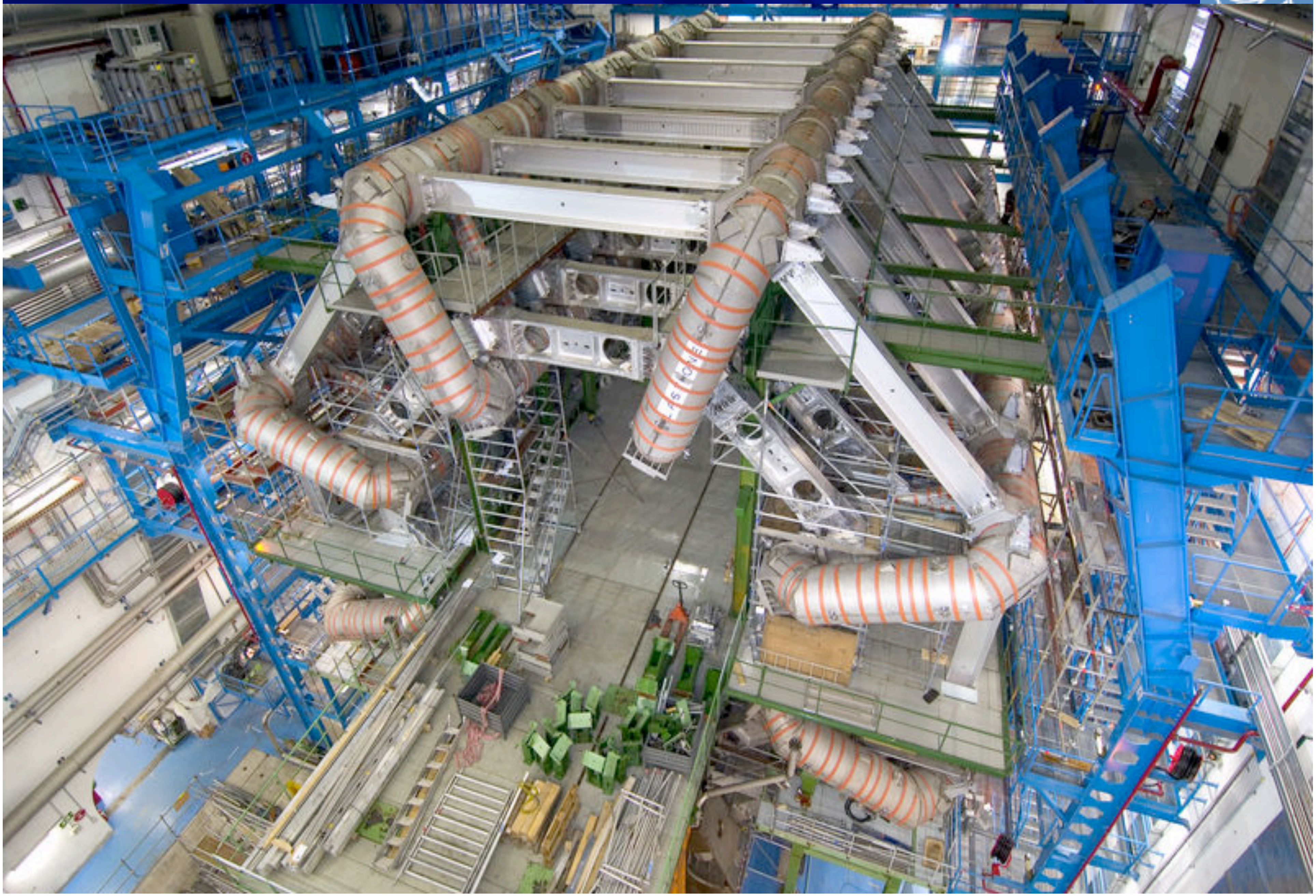
8 coils interconnected with an aluminum warm structure

- 20 m diam. x 25 m length
- 8200 m^3 volume
- 170 t superconductor
- 700 t cold mass
- 1320 t total weight
- 90 km superconductor
- 20.5 kA at 4.1 T
- 1.55 GJ stored Energy

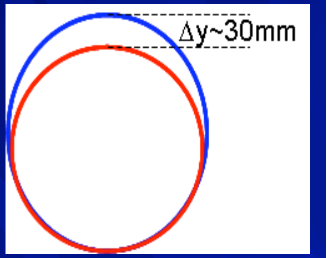
BT Mechanical Assembly

- ♦Difficult but safe manipulations
- ♦Use of 2 lifting frames
- ♦Hydraulic winch with load capacity 190T (subcontracted)





Coils positioning and release



- *Coils positioned on an ellipse, DY(vertical)=30mm to anticipate the sagging*
  - ✓ DY = 24 +/- 6 mm due to its own weight and the weight of the
  - ✓ muon spectrometer (according to various FEA calculations)
- *Release of the hydraulic system and come to a circular shape*
  - ✓ Detailed procedure and control sheets
  - ✓ Many cross-checks before the operation
  - ✓ Re-tightening of all bolts
  - ✓ Checking of all bolt connections
- *Release by steps of 2 mm until the pressure ~ 0 bar (27th September)*
  - ✓ Measured movements : DY = 18 mm ; DX = 7 mm
  - ✓ No increase of the tension in the bolts
  - ✓ Deformation < 1 mm at the level of the feet

Perfect and as calculated!

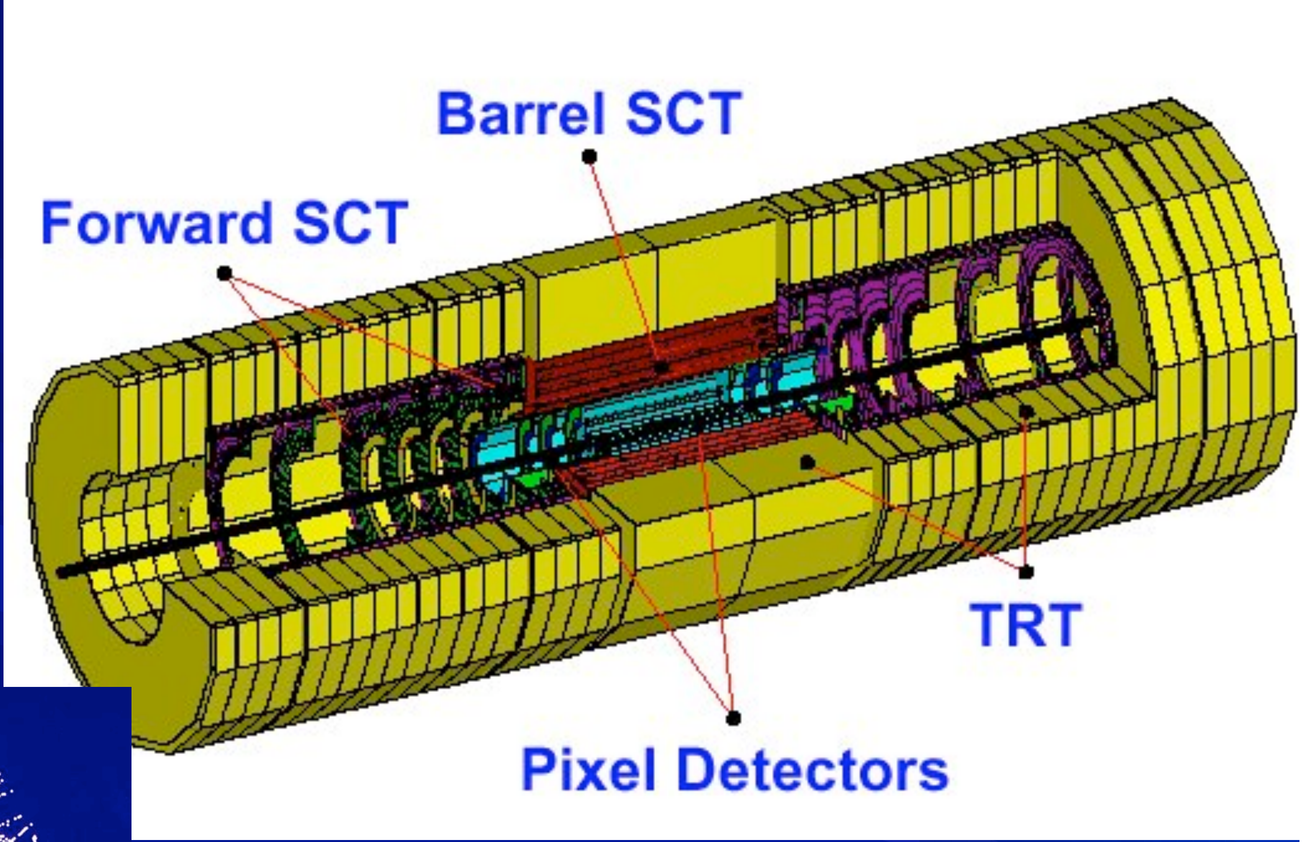
Inner Detector (ID)

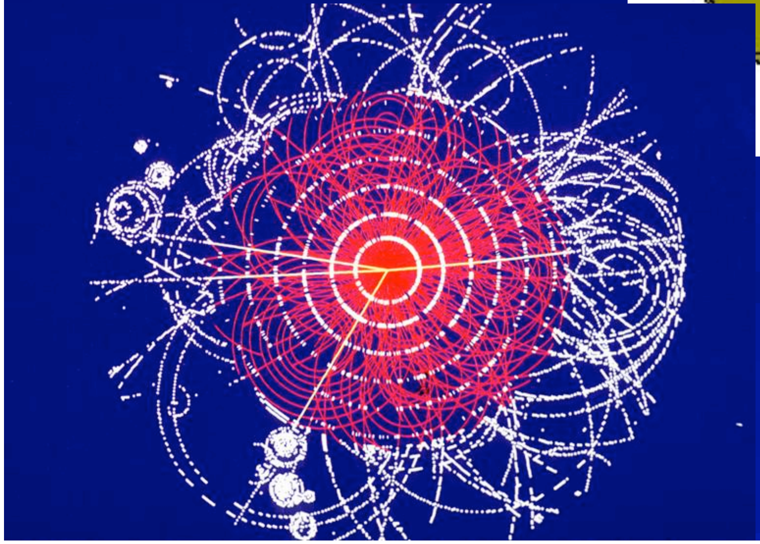
The Inner Detector (ID) is organized into four sub-systems:

Pixels (0.8 10^8 channels)

Silicon Tracker (SCT) (6 10^6 channels)

Transition Radiation Tracker (TRT) (4 10^5 channels)





Pixels

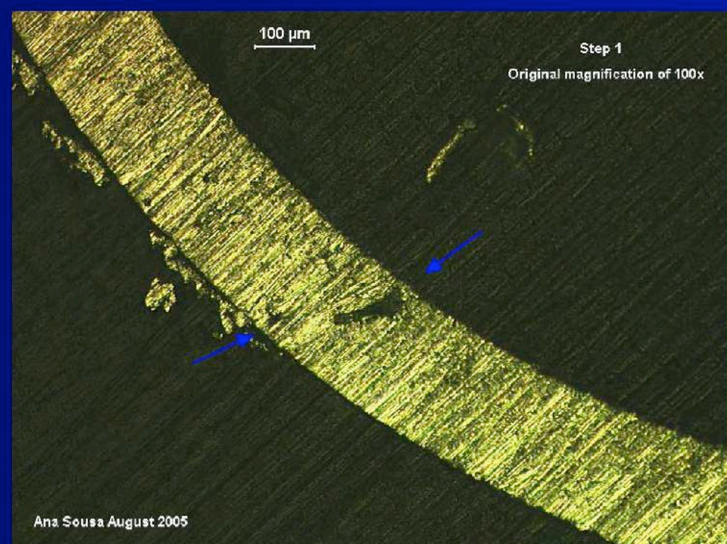
After excellent progress on the Pixel projects three technical problems have affected the schedule:

- Faulty potting of controller chip on a fraction of barrel modules (solved)
- Delamination of a fraction of barrel stave supports (solved)

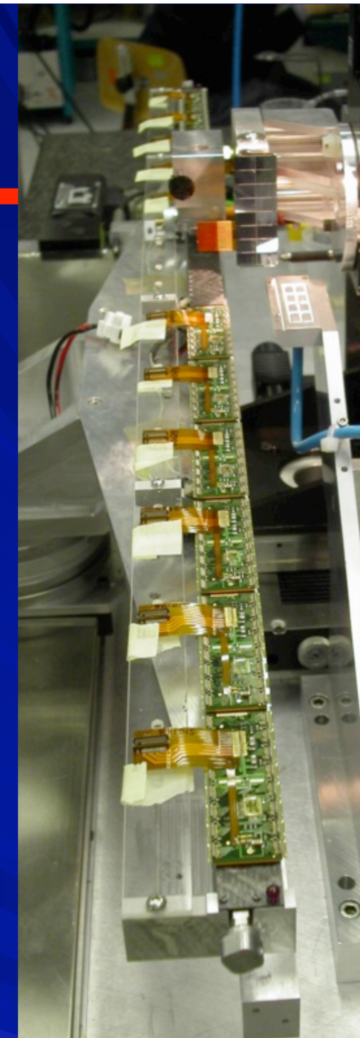
- Corrosion leaks in the barrel cooling tubes (highest priority is given to work out and implement an optimum strategy for repair and rebuilding of staves)

This means that there is a schedule risk for the installation of a 3-layer system in time for the start-up (the Pixel sub-system can be installed independently from the rest of the Inner Detector)

The installation schedule has been adapted to accommodate a late availability

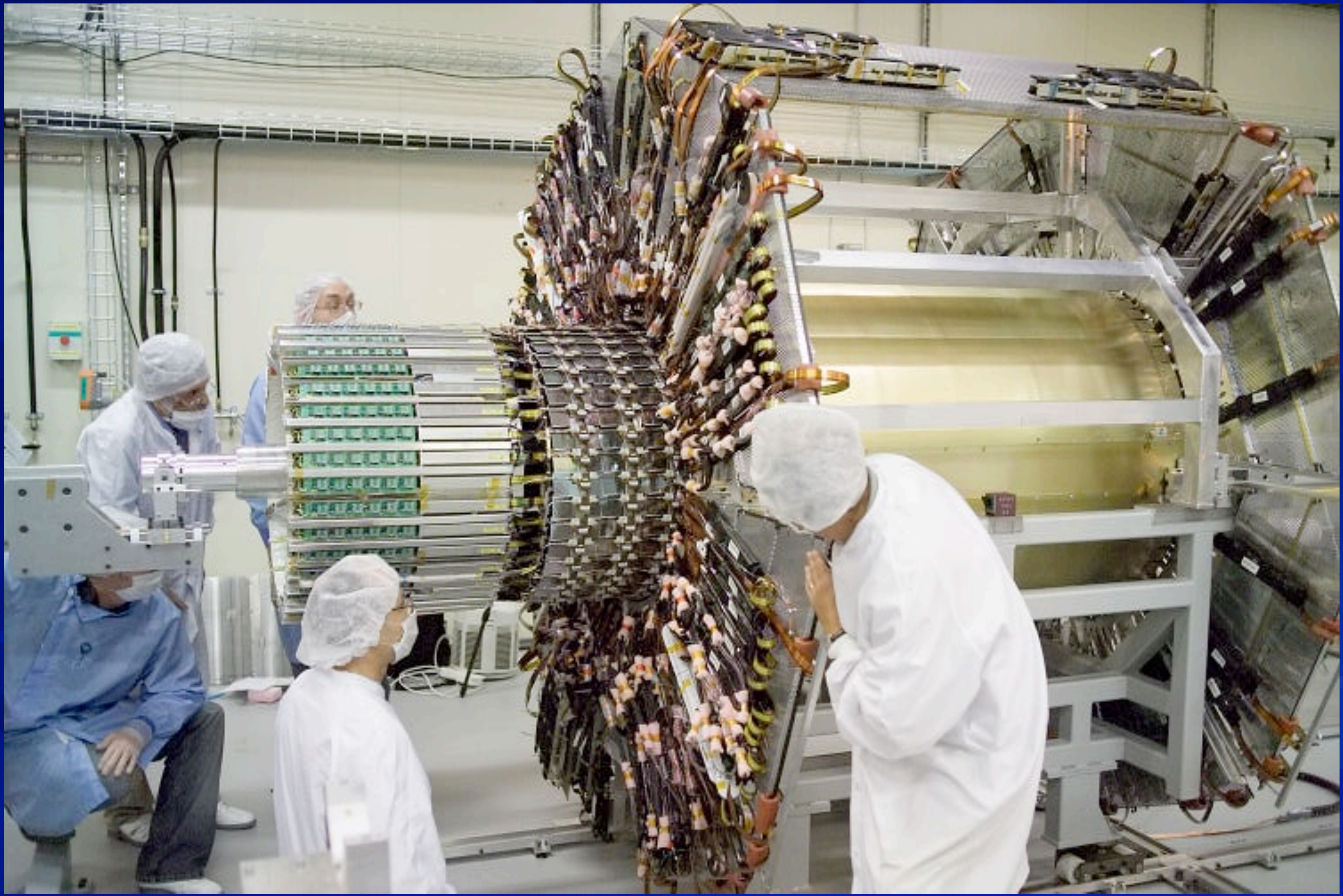


Example of a galvanic corrosion hole that is opening

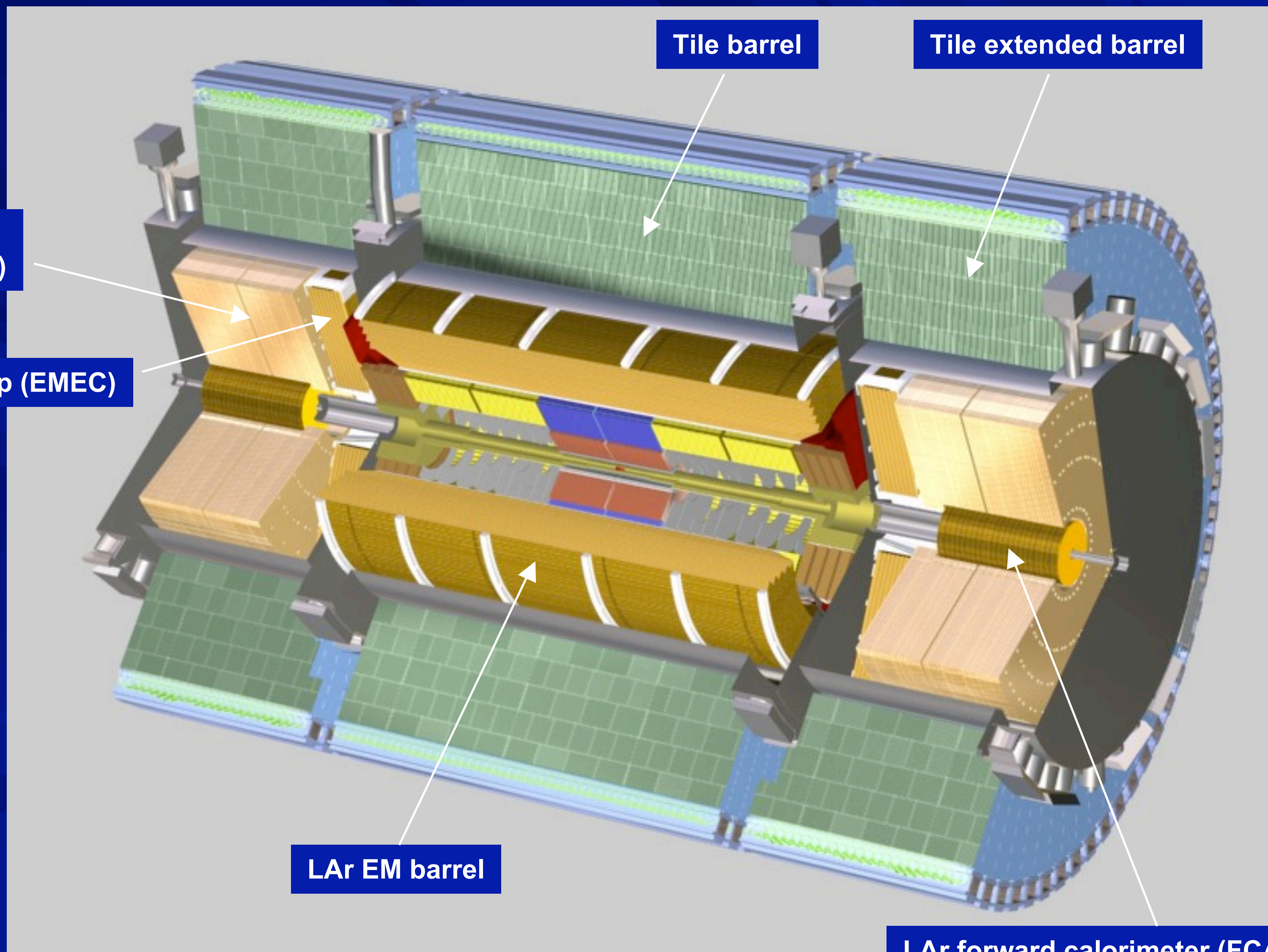


Completed barrel stave

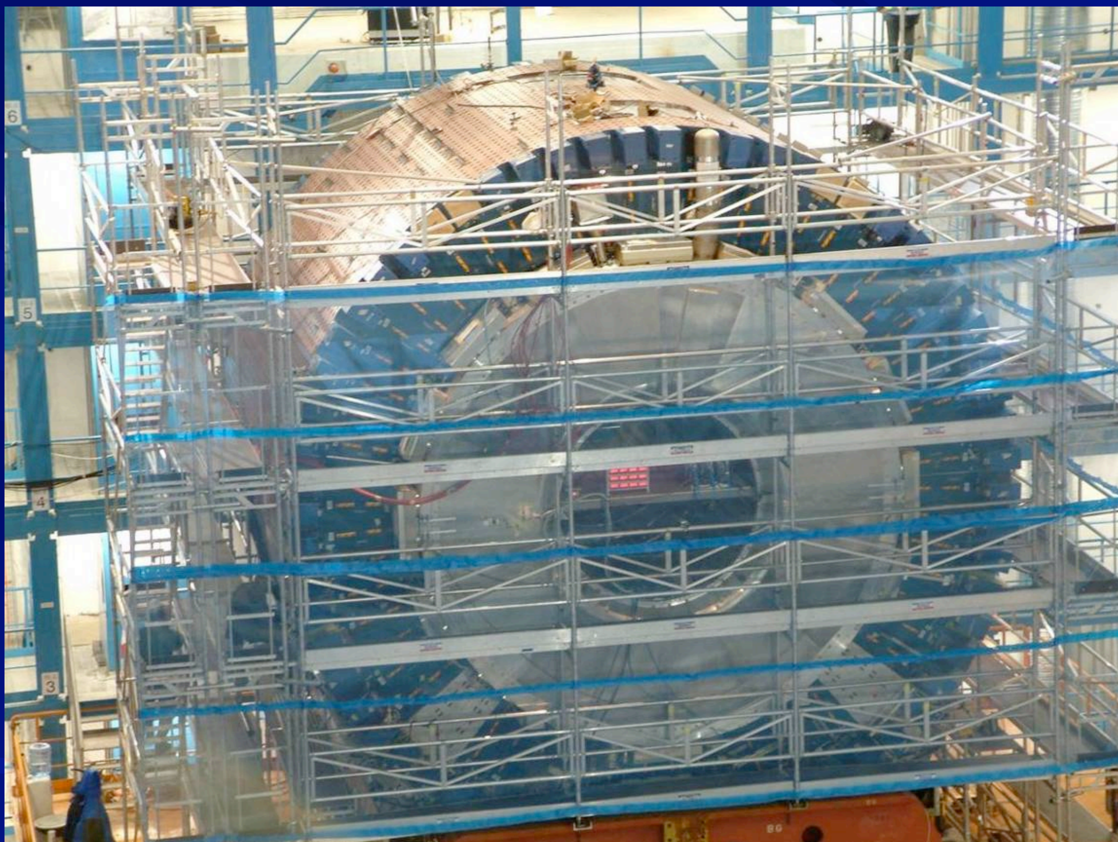
Insertion of the 3rd cylinder (out of the four) into the barrel SCT



LAr and Tile Calorimeters

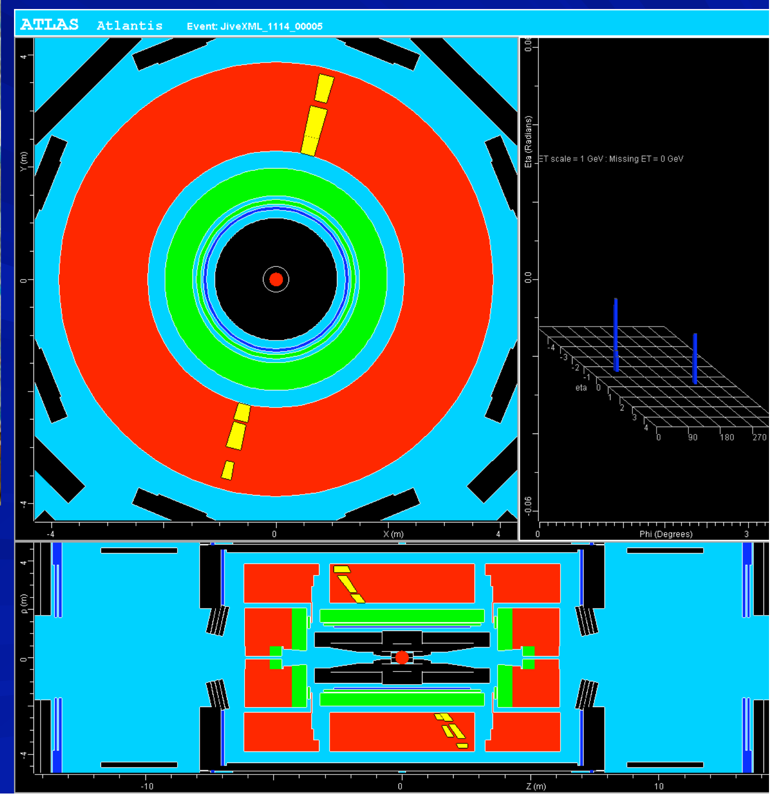


Barrel LAr and Tile Calorimeters



The barrel LAr and Tile calorimeters have been since some time in the cavern in their ‘garage position’ to be moved into their final position at the end of this month

A cosmics muon registered in the barrel Tile calorimeter



The delicate transport of the first LAr End-Cap to point-1 (22nd Sep)

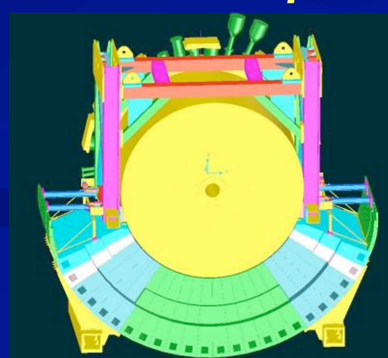
The lower part of the Extended Barrel Tile Calorimeter and the LAr End-Cap are ready for the lowering into the cavern (side C)

LAr and Tile Calorimeter End-Caps

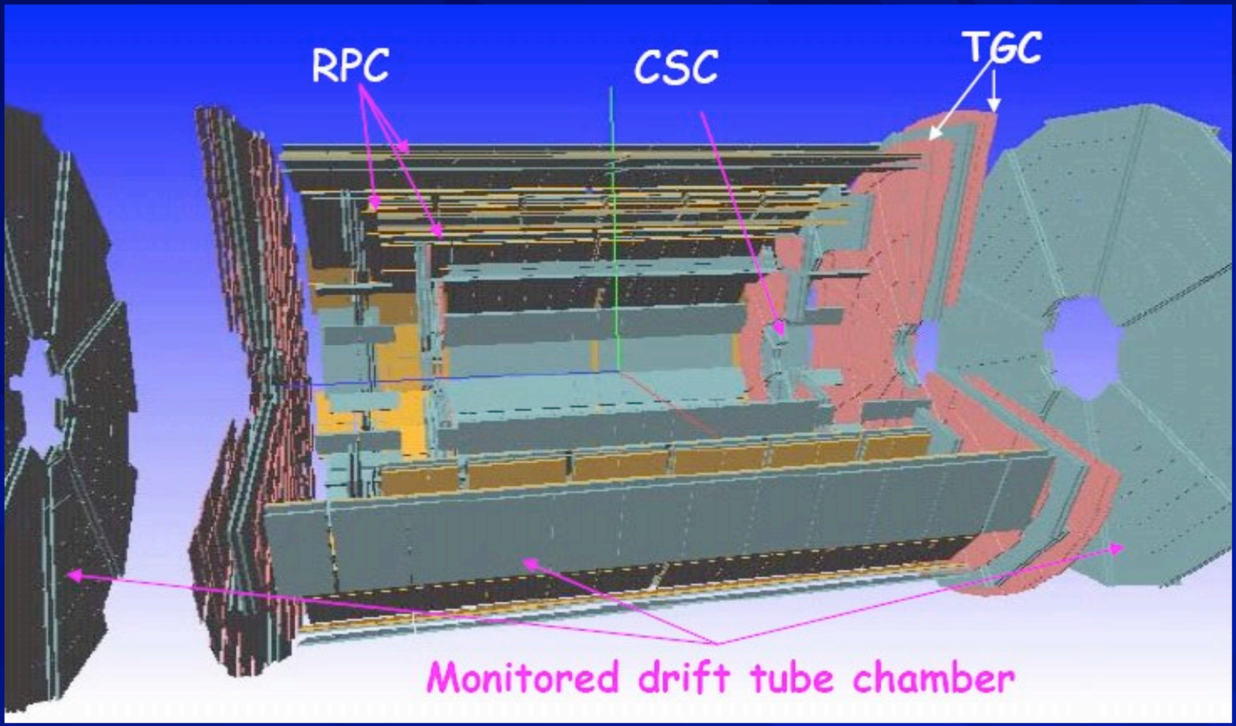
Next major activities:

End-Cap C installation from Nov 05 → Jan 06

End-Cap A installation from Jan 06 → Mar 06



Muon Spectrometer Instrumentation



The Muon Spectrometer is instrumented with precision chambers and fast trigger chambers

A crucial component to reach the required accuracy is the sophisticated alignment measurement and monitoring system

Precision chambers:

- MDTs in the barrel and end-caps
- CSCs at large rapidity for the innermost end-cap stations

Trigger chambers:

- RPCs in the barrel
- TGCs in the end-caps

At the end of this year the huge and long effort of series chamber production in many sites will be completed for all chamber types

End-cap muon chamber sector preparations

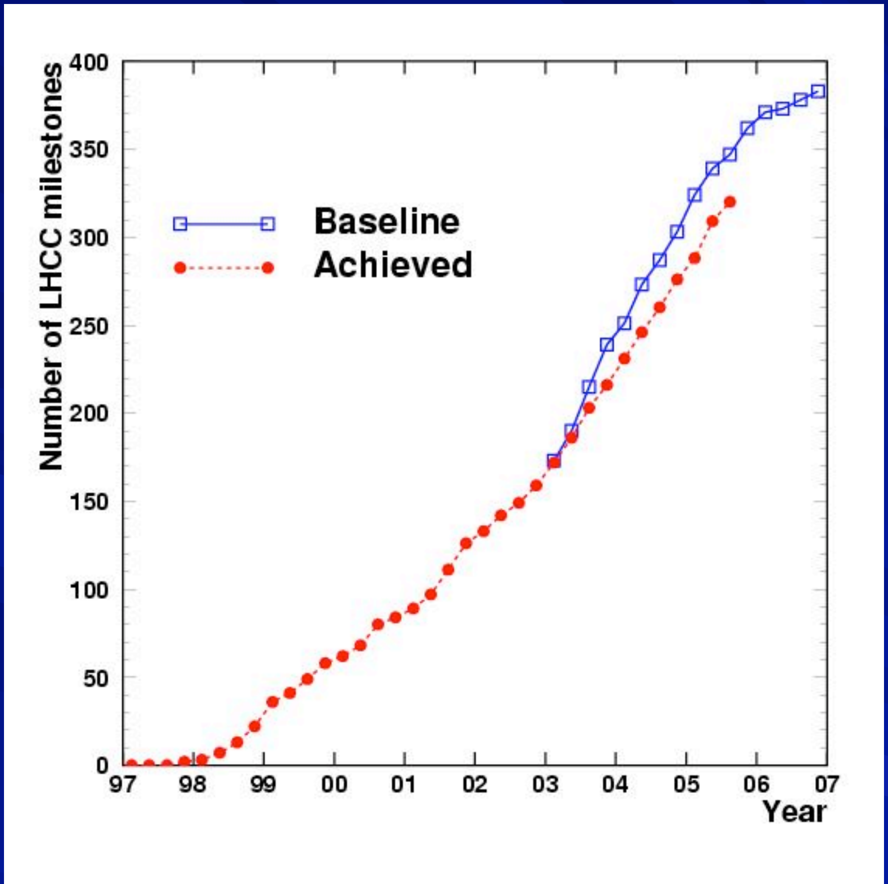
72 TGC and 32 MDT ‘Big-Wheel’ sectors have to be assembled

This work is now in full swing in the Hall where previously the Barrel Toroid and the LAr integration and tests were done

First ‘Big Wheel’ end-cap muon MDT sector assembled in Hall 180

First ‘Big Wheel’ end-cap muon TGS sector assembled in Hall 180

LHCC Milestones

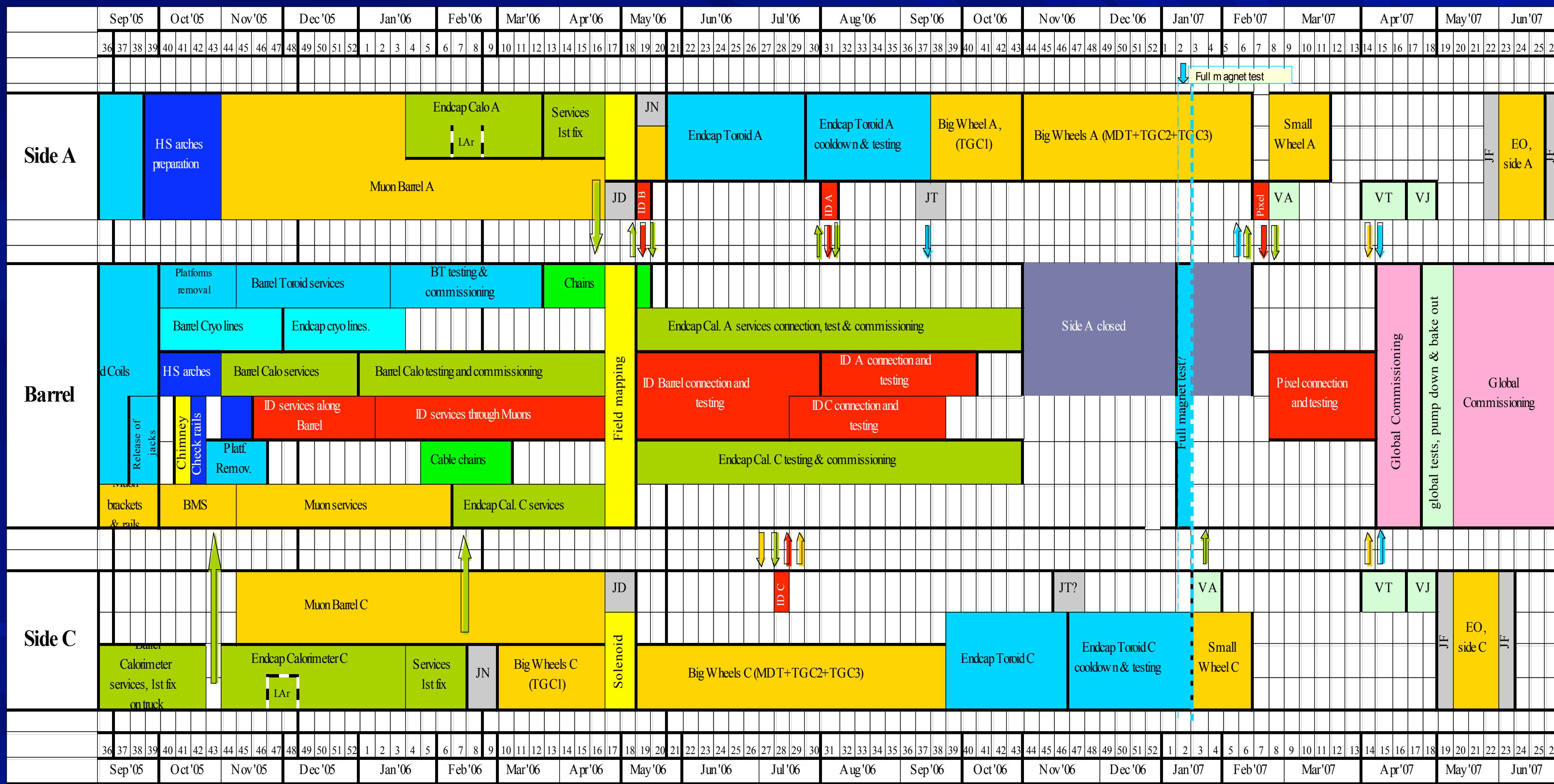


<u>Construction issues and risks ('Top-Watch List')</u>

A list of these issues is monitored monthly by the TMB and EB, and it is publicly visible on the Web, including a description of the corrective actions undertaken:

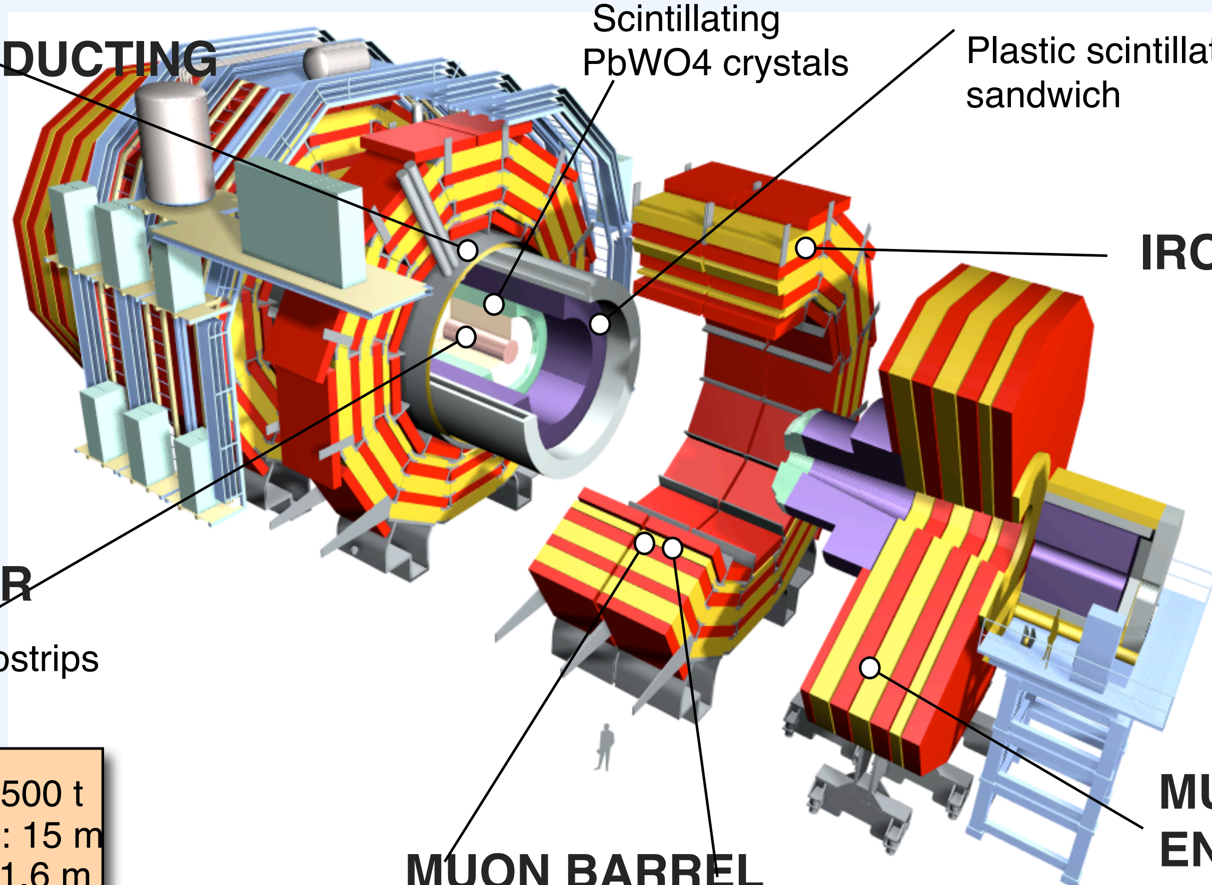
http://atlas.web.cern.ch/Atlas/TCOORD/TMB/

Summary representation of the installation activities in the experimental cavern



The CMS Detector

(Spokesperson Michel Della Negra)



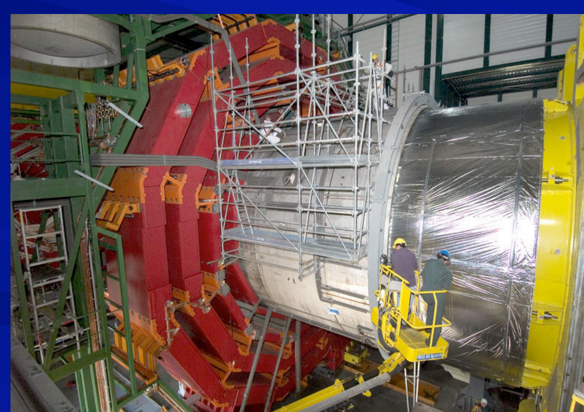
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

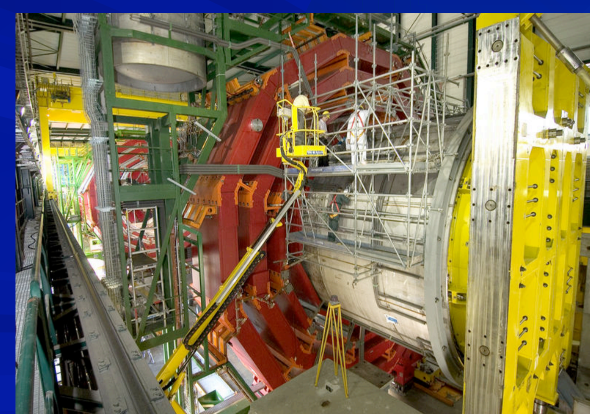
Underground UXC Cavern (5 Sept)

Coil Swiveling and Insertion

Swiveling of coil carried out on 25 Aug.

Coil inserted 14 Sep.



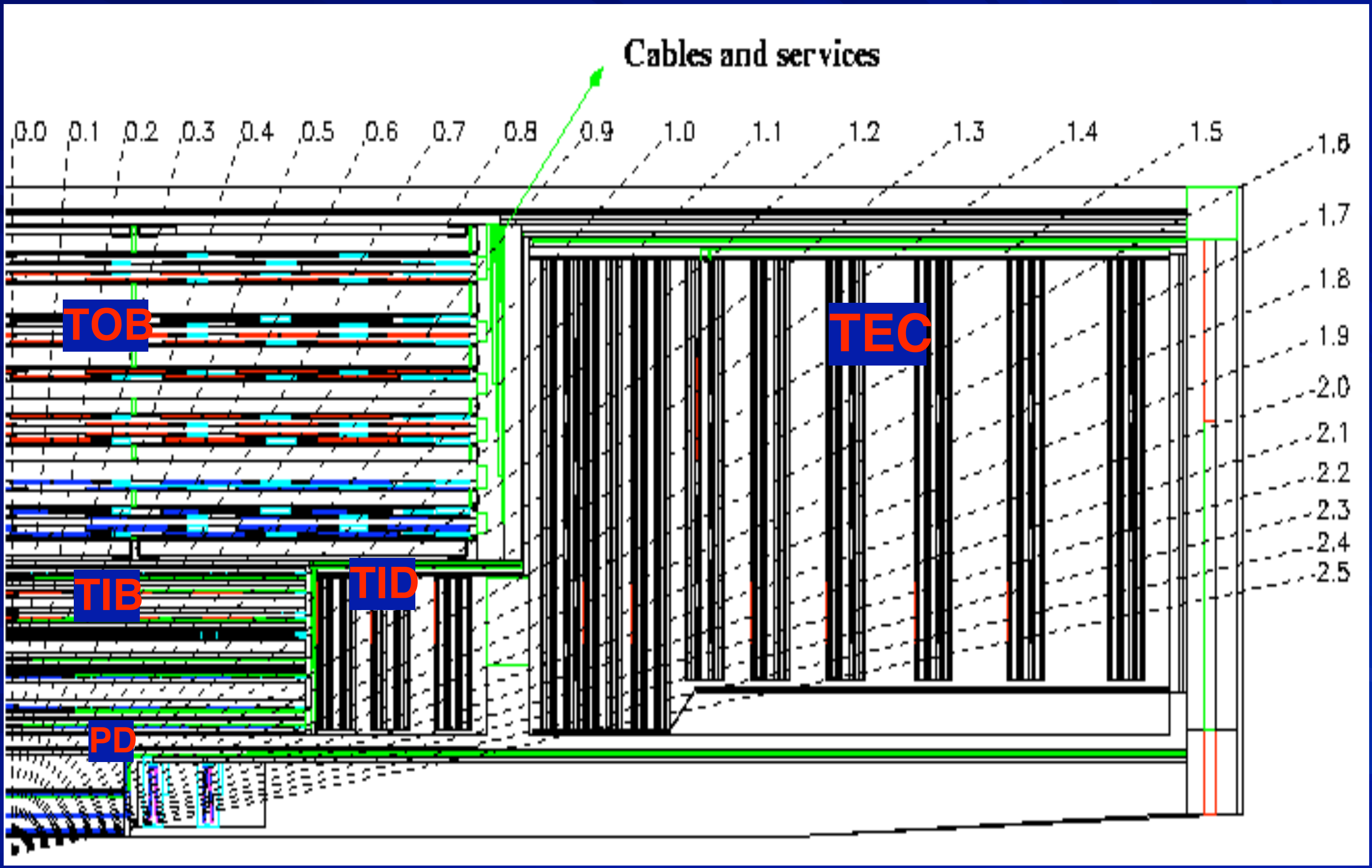


Platform disconnected from Coil (28 Sep)

Swivelling of inner vac tank: ~ 20 Oct

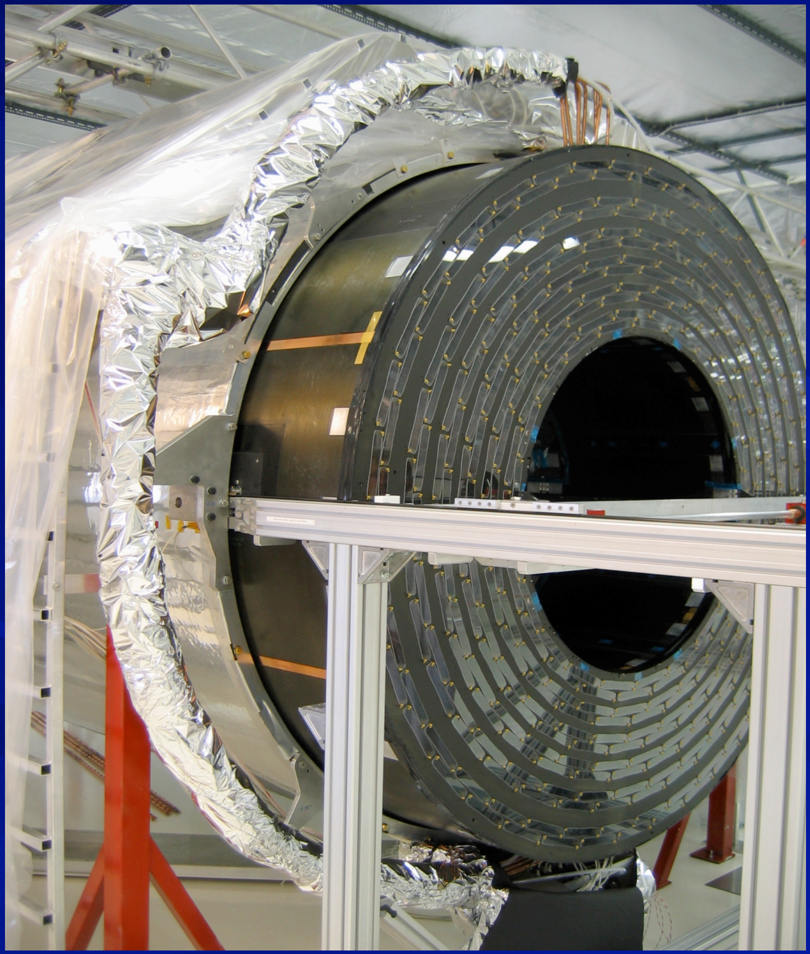
Coil cool-down and start of electrical tests : Jan 06

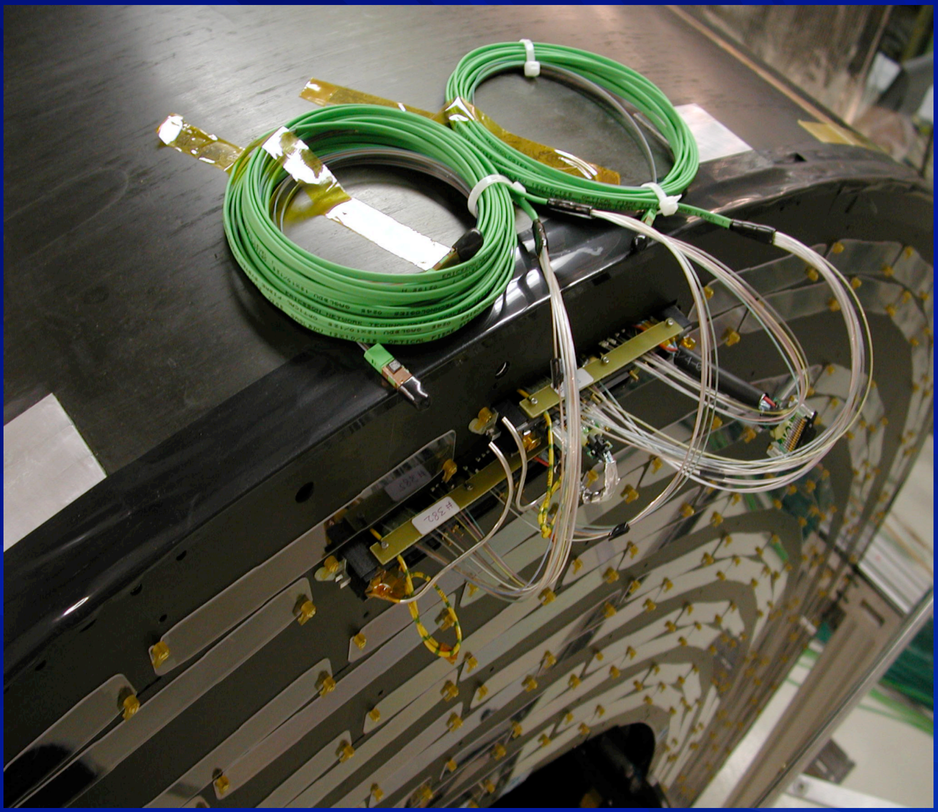
Inner Tracker



Tracker Outer Barrel

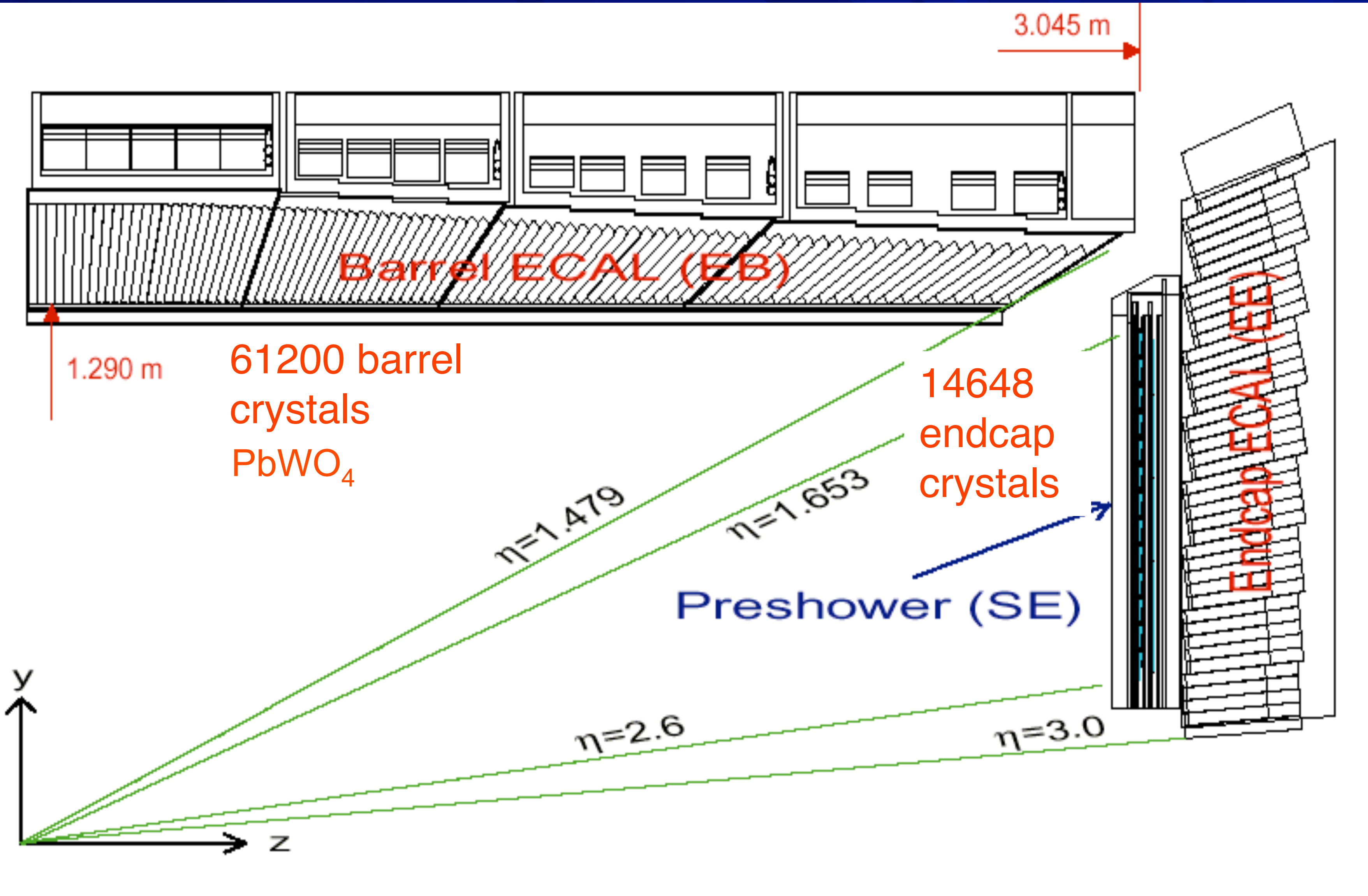
The TOB Support Structure partially inserted into the Tracker Support Tube



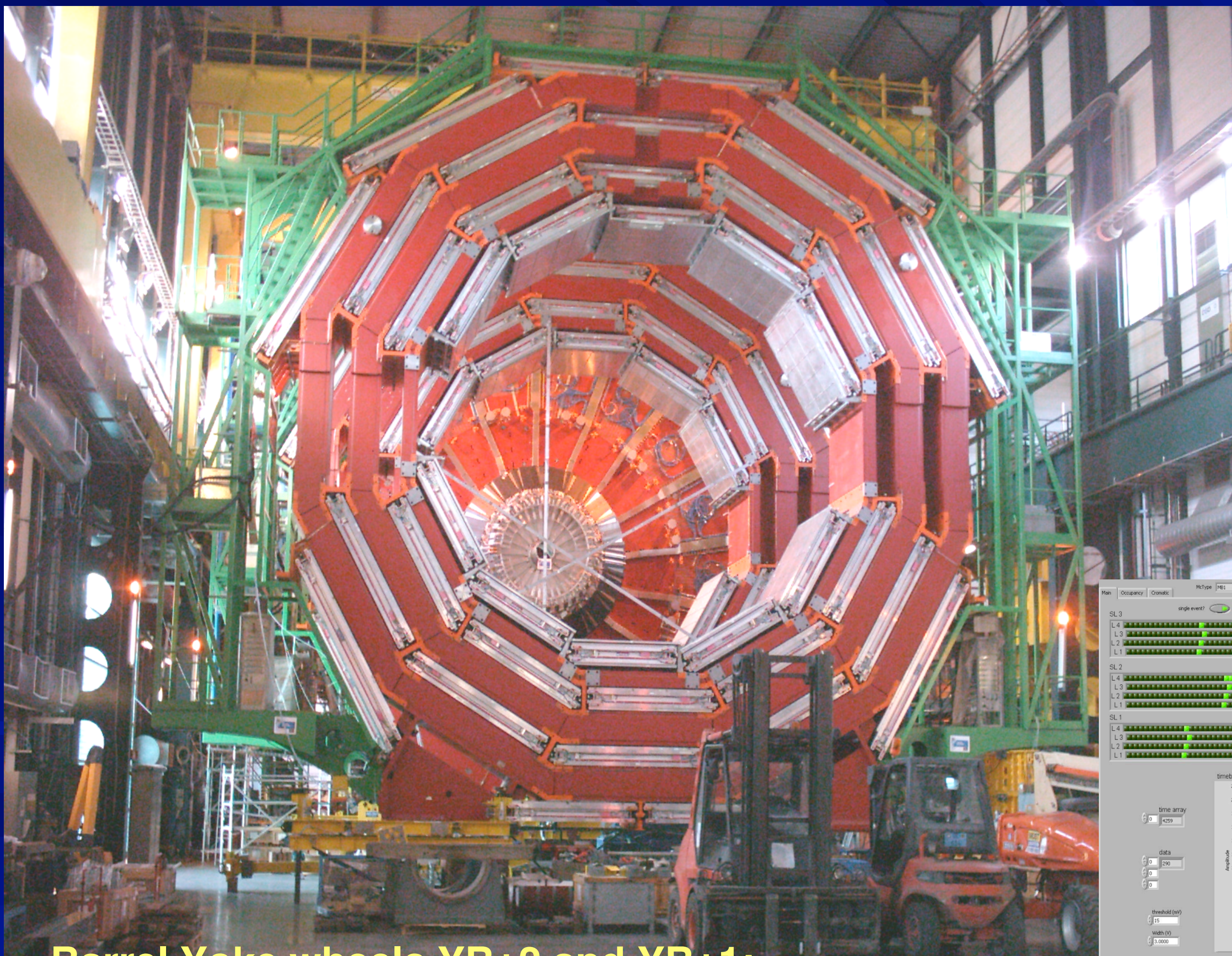


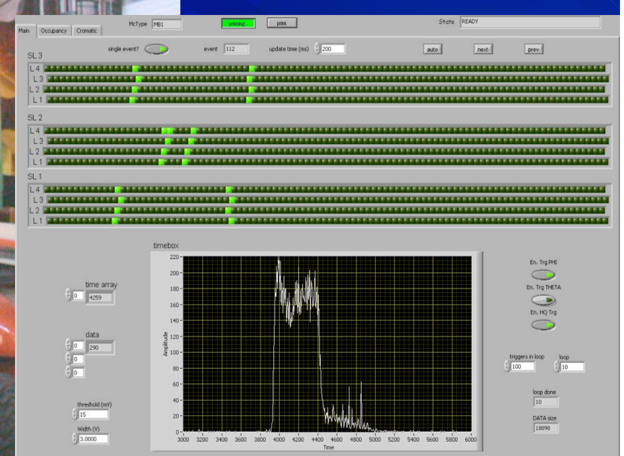
The Trial Insertion of Two RODs into the TOB Structure

Electromagnetic CALorimeter



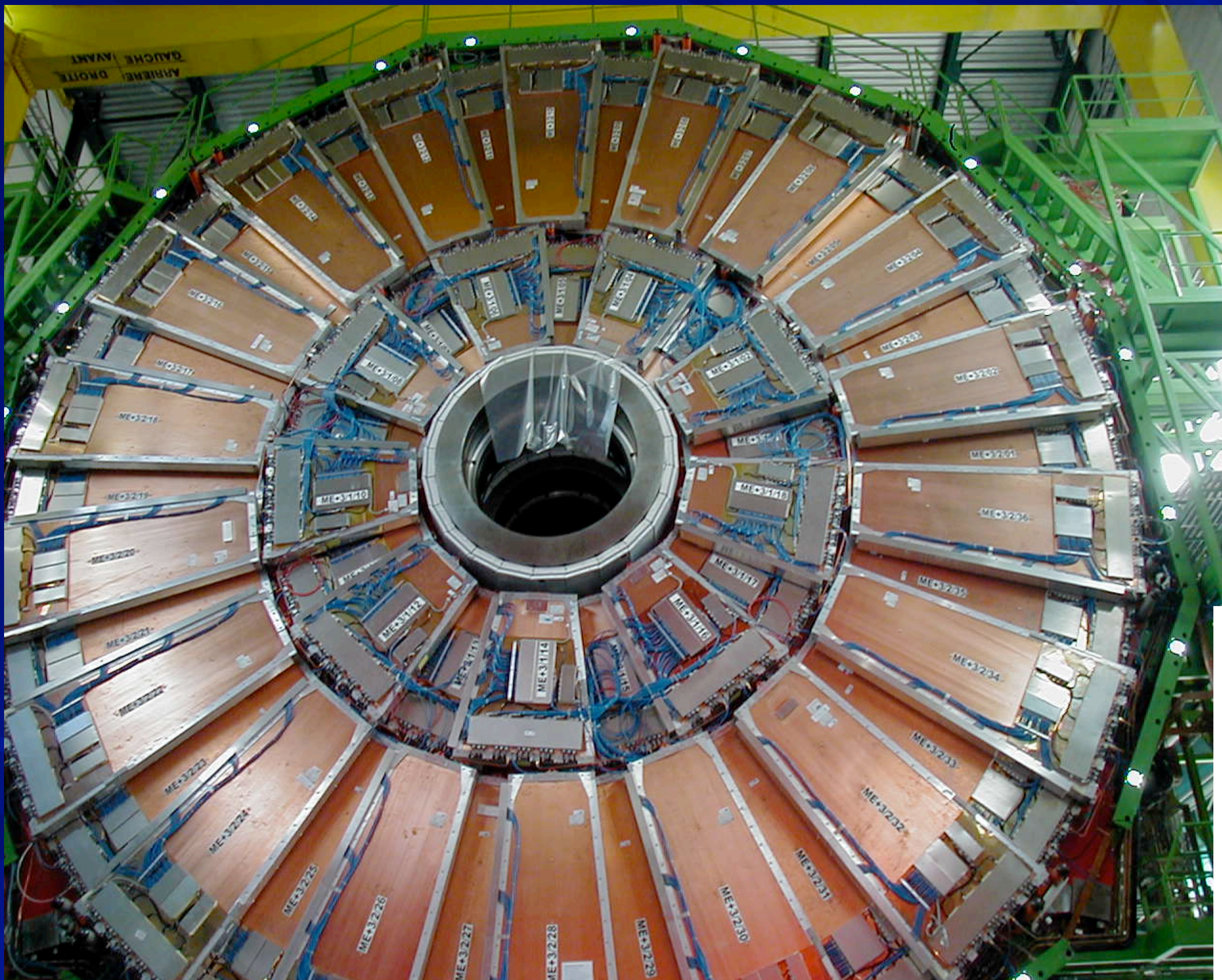
Barrel Muons: DriftTubes Assembly and Installation

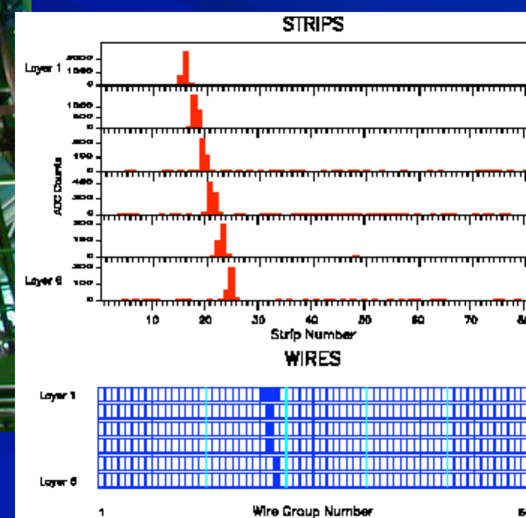




Barrel Yoke wheels YB+2 and YB+1:
80 (out of 210) DT/RPC Ch. Installed; 40 Ch. commissioned

Endcap Muons: ME2, ME3 and ME4 stations





CMS Schedule

Currently see a delay of an average of 6 weeks wrt v34.2. Will try to regain time during repetitive operations after lowering in second half of 2006.

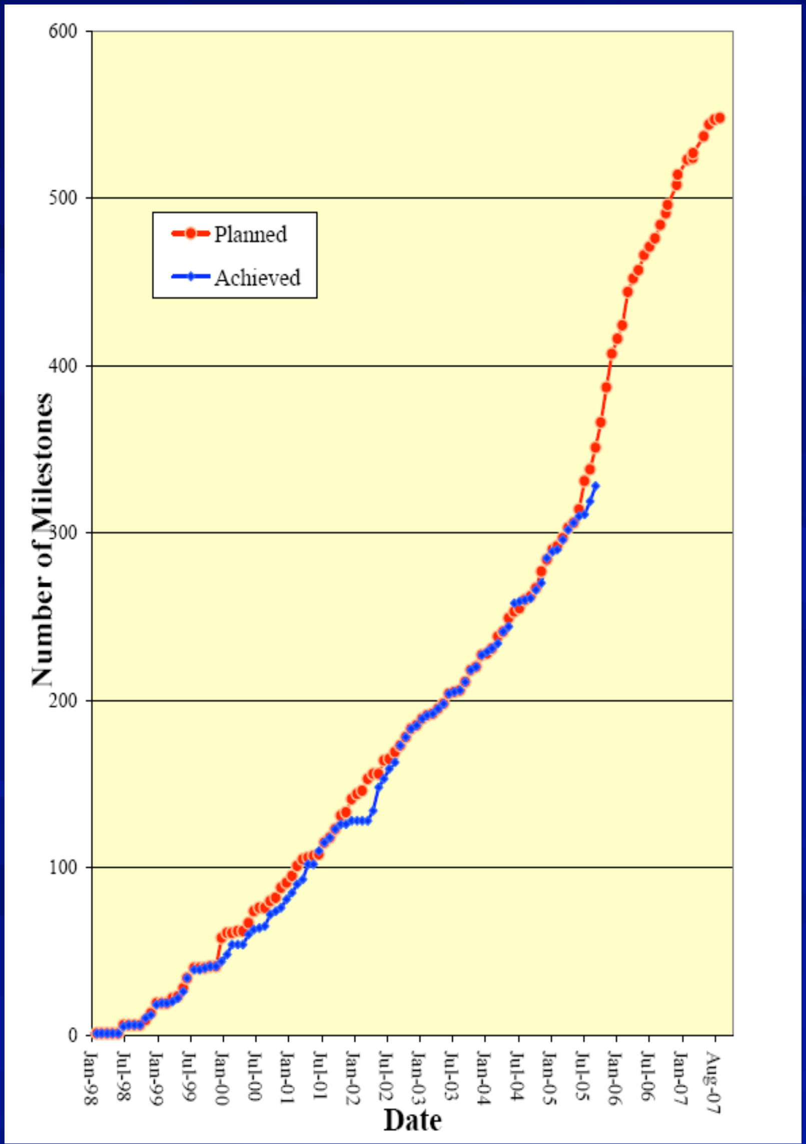
	v34.2	**Estimate**
• Magnet test on surface start	Nov 05	Feb 06
• Start Lowering CMS (HF first)	Feb 06	Apr 06
• ECAL barrel EB+ installation	Mar 06	May 06
• ECAL: EB- installation & cabling	Oct 06	Oct 06
• Tracker installation + cabling start	Nov 06	Nov 06
• Beampipe Installation	Mar-Apr 07	Mar-Apr 07
• CMS “ready to close” for beam	15 Jun 07	15 Jun 07
• CMS “ready for beam”	30 Jun 07	30 Jun 07

During first shutdown after pilot physics run:

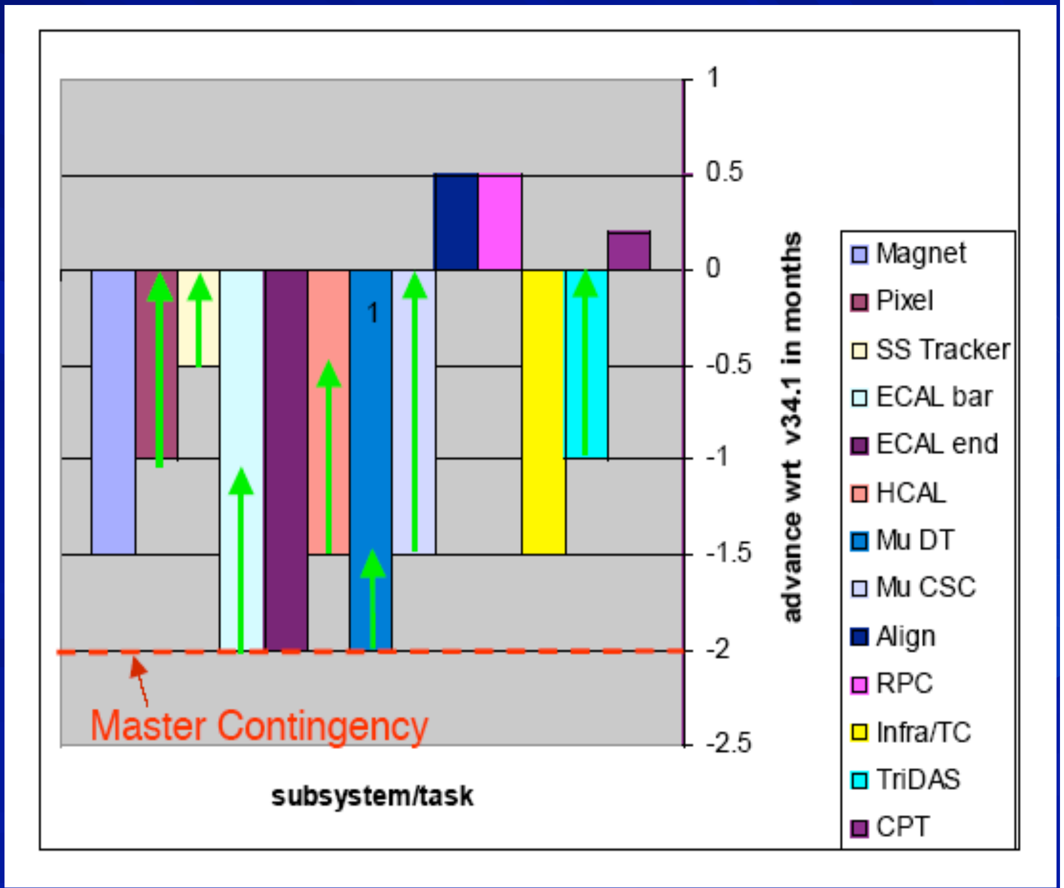
• Pixel Tracker installation	Dec 07	Dec 07
• EE/ES installation	Dec07/Feb 08	Dec07/Feb 08

Milestones

Milestone completion wrt v34.2



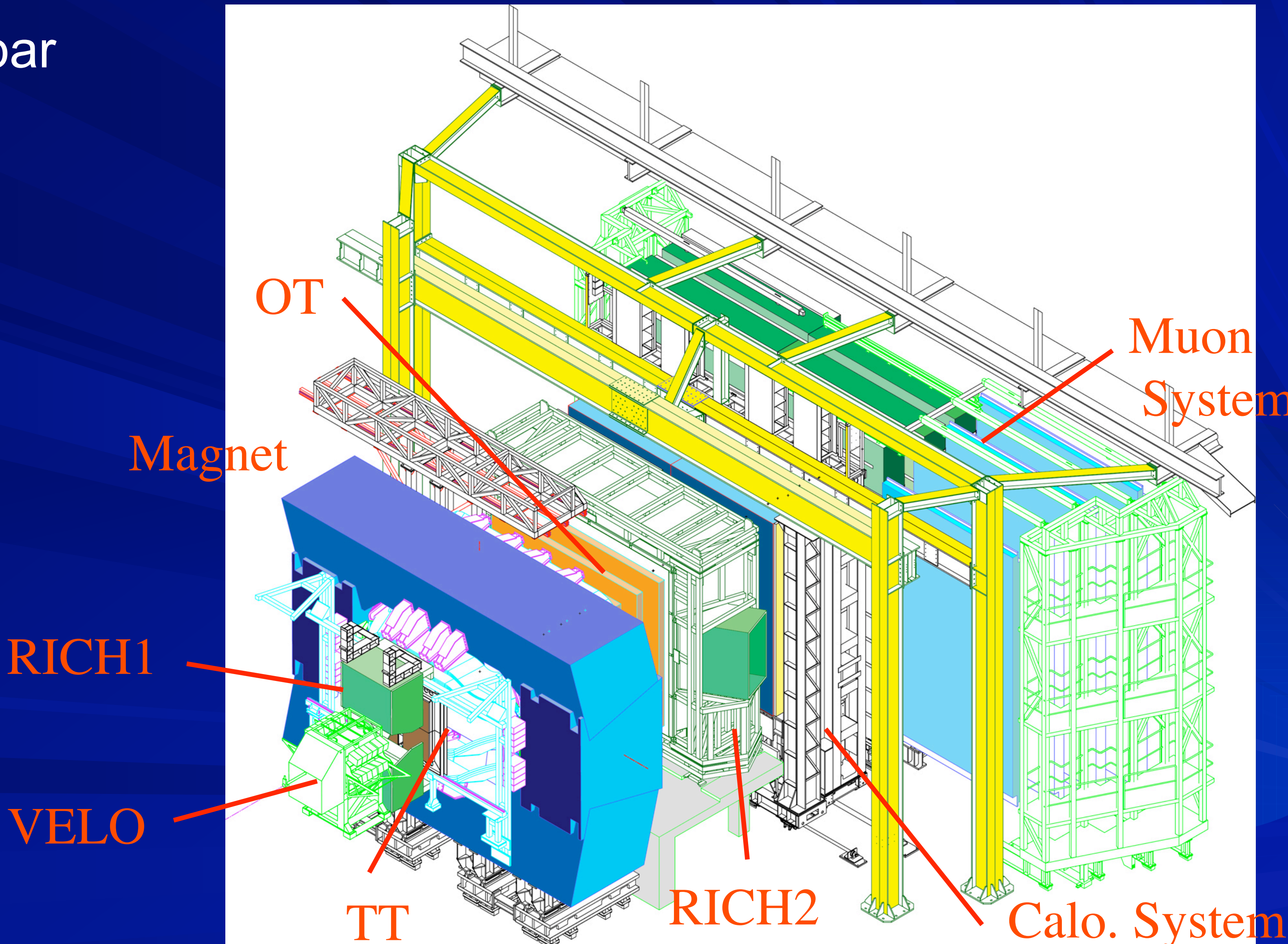
Current average delay of ~ 1-2 months.
Green arrows show estimated internal contingency to recover any delay



LHCb Spectrometer

(spokesman Tatsuya Nakada)

gg→b bbar



Beam Pipe

-25 mrad Be section completed

-10 mrad Be

1st section being tested at IHEP, Protvino

-10 mrad Be

2nd section under construction by Kompozit, Moscow

- All the other components are also under construction

VErtex LOcator

VELO tank installed in the support frame and connected to the vacuum system

CO_2 cooling capillaries

feedthrough flanges

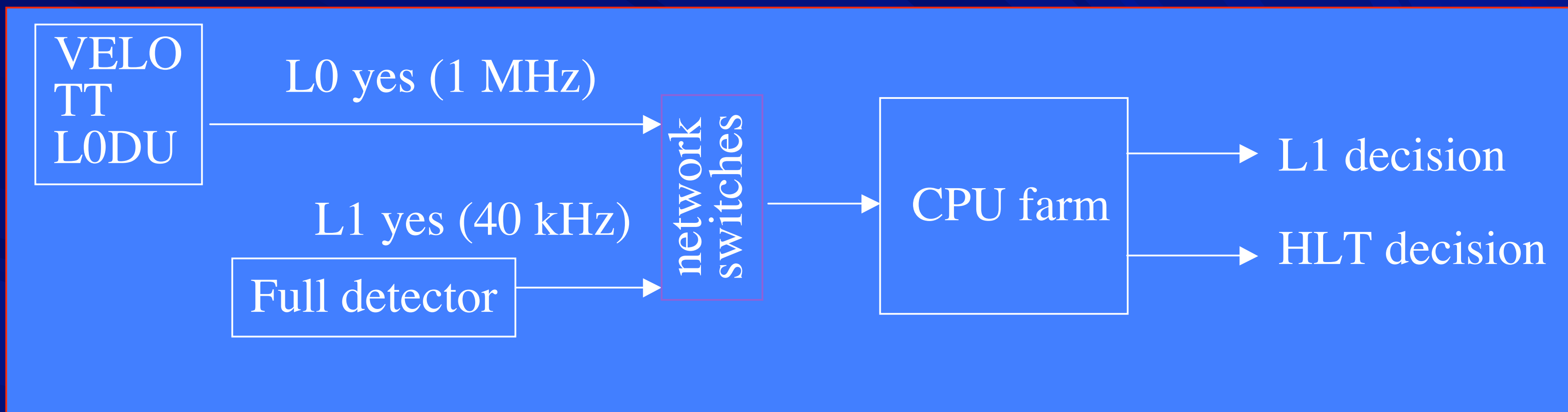
r-sensor

All the parts are now being produced

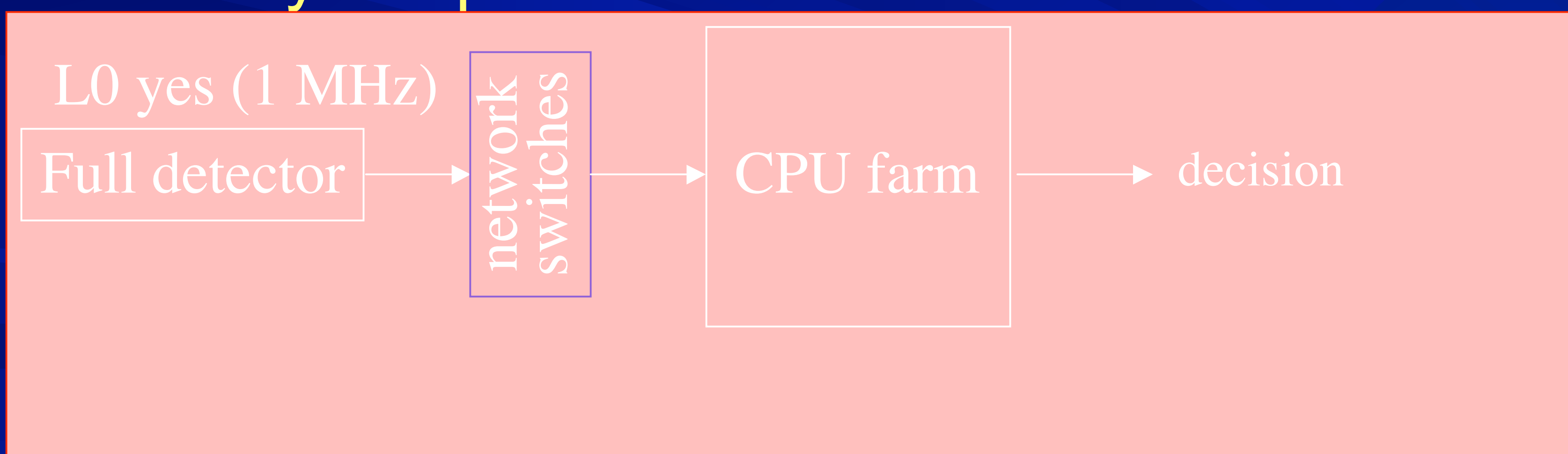
hybrid and module support

L-1 and HLT hardware now completely unified

Old scheme

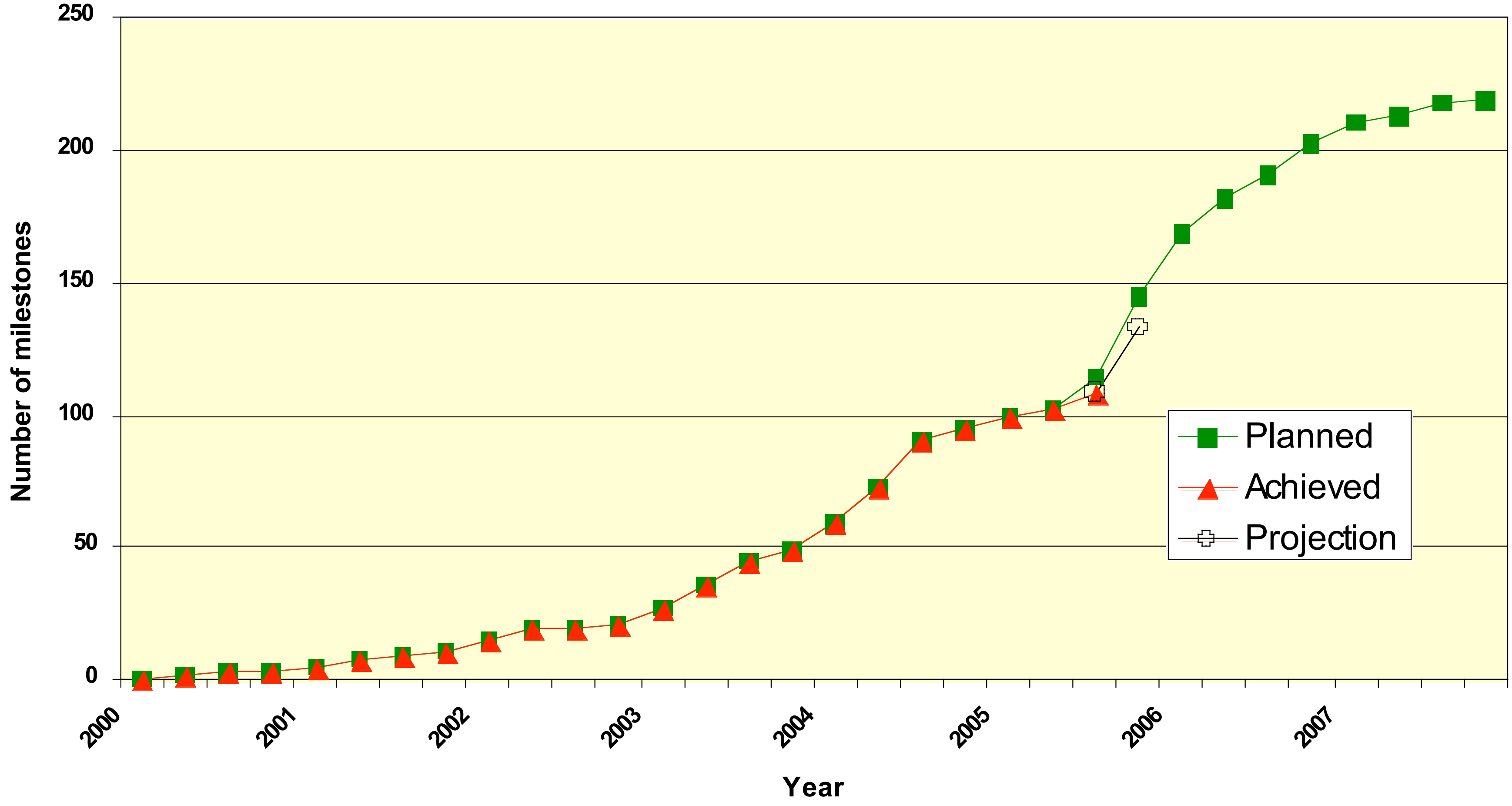


Newly adopted 1 MHz readout scheme



This was foreseen as an upgrade, but the cost of the network switches has dropped faster than anticipated.

LHCC Milestones (October 2005)

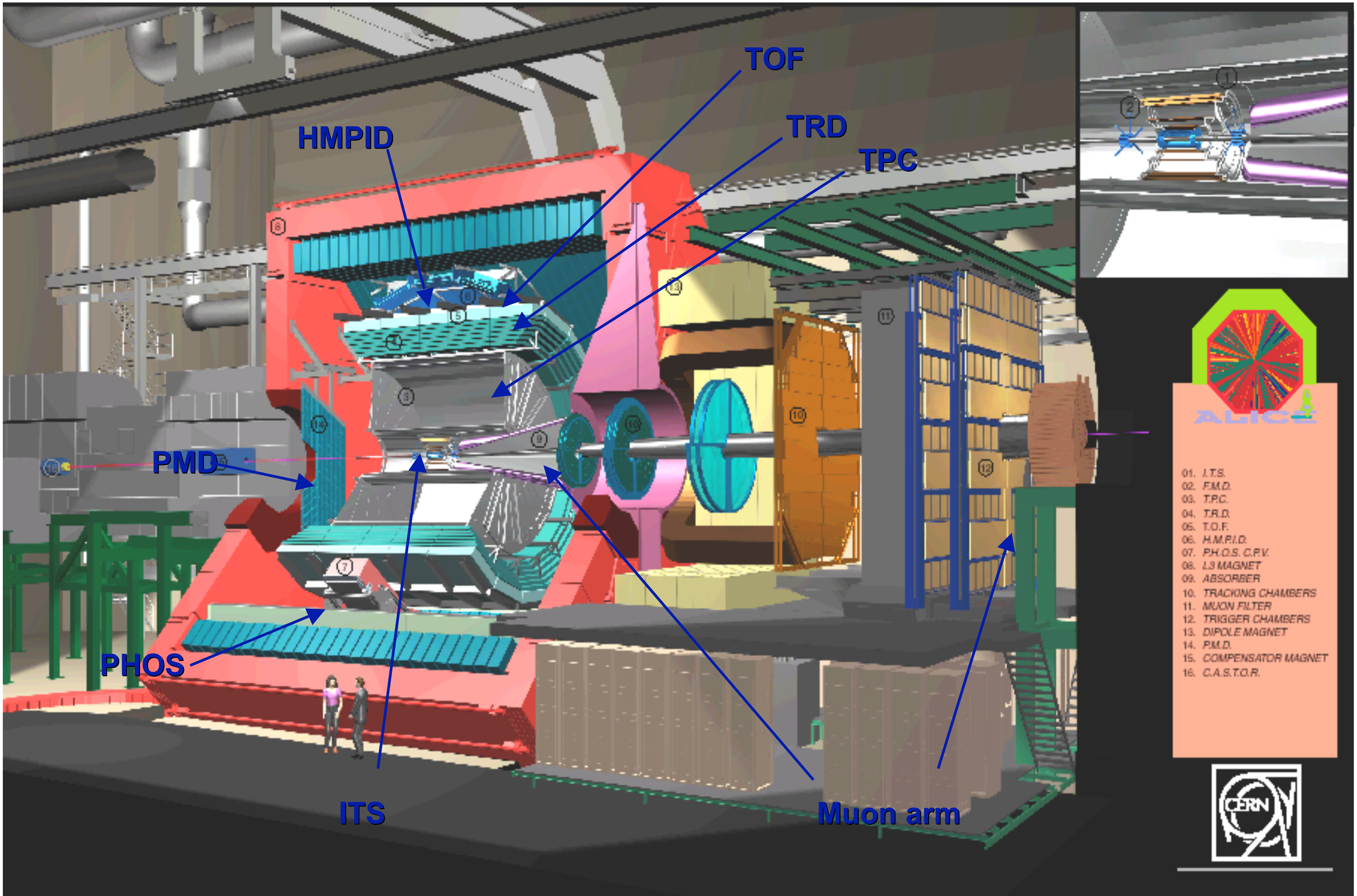


LHCb

Production, installation and commissioning of all the subsystems are progressing well

No problem with the TT and ST sensor delivery any more

Still tight schedule for VELO sensors, RICH1 mechanics, HPD's and Muon chambers

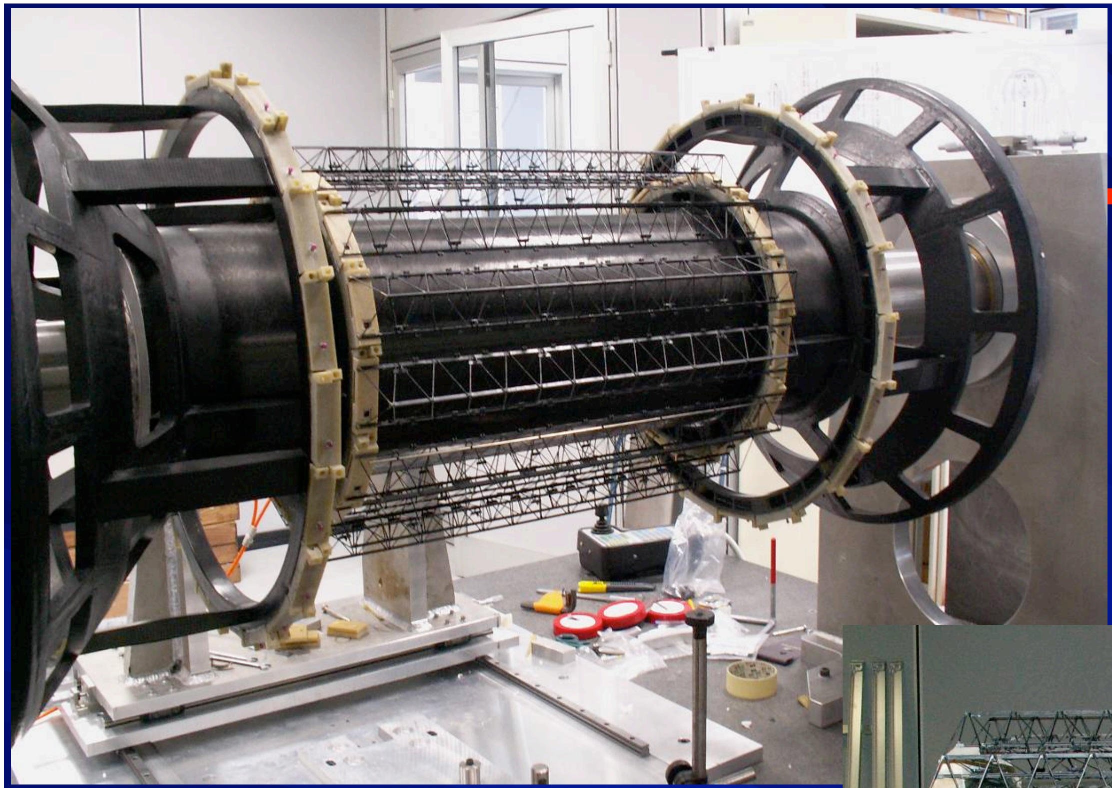


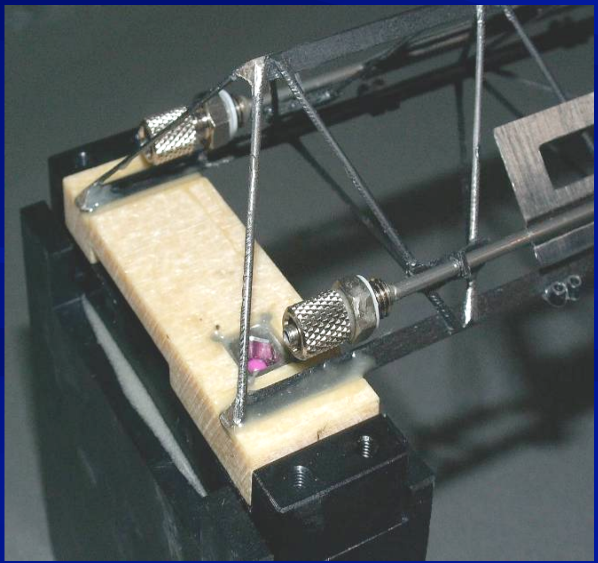
ALICE Detector

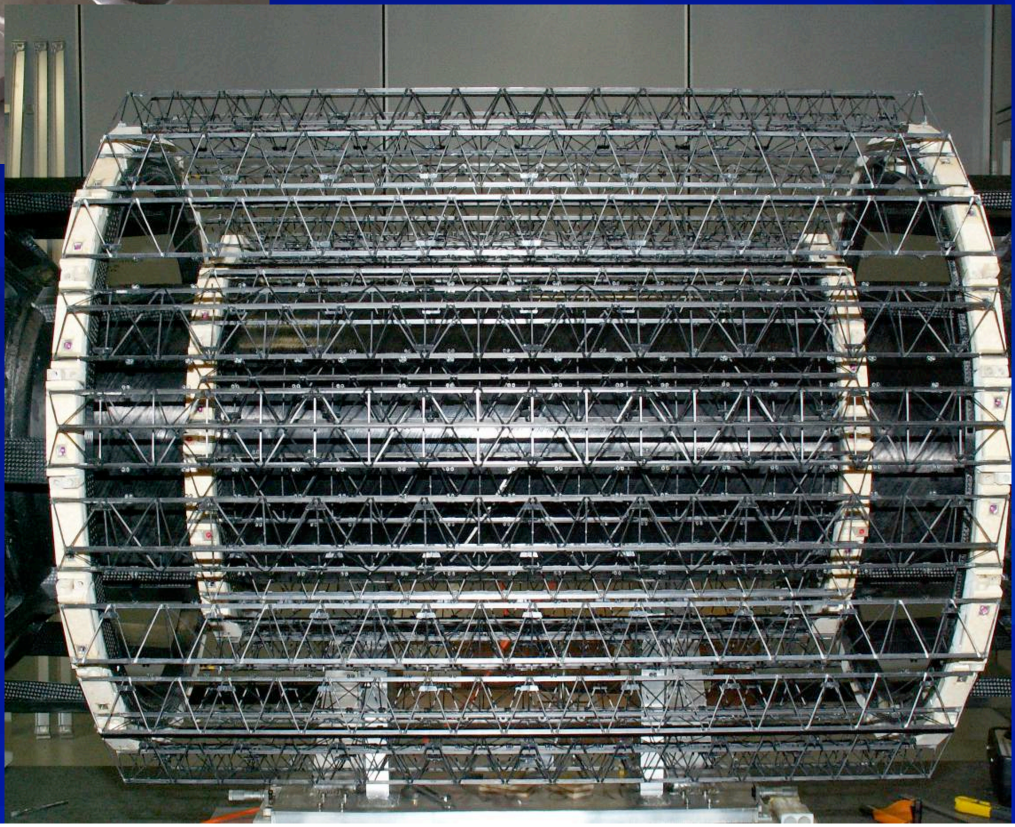
(spokesman Juergen Schukraft)

Space Frame LOAD TEST

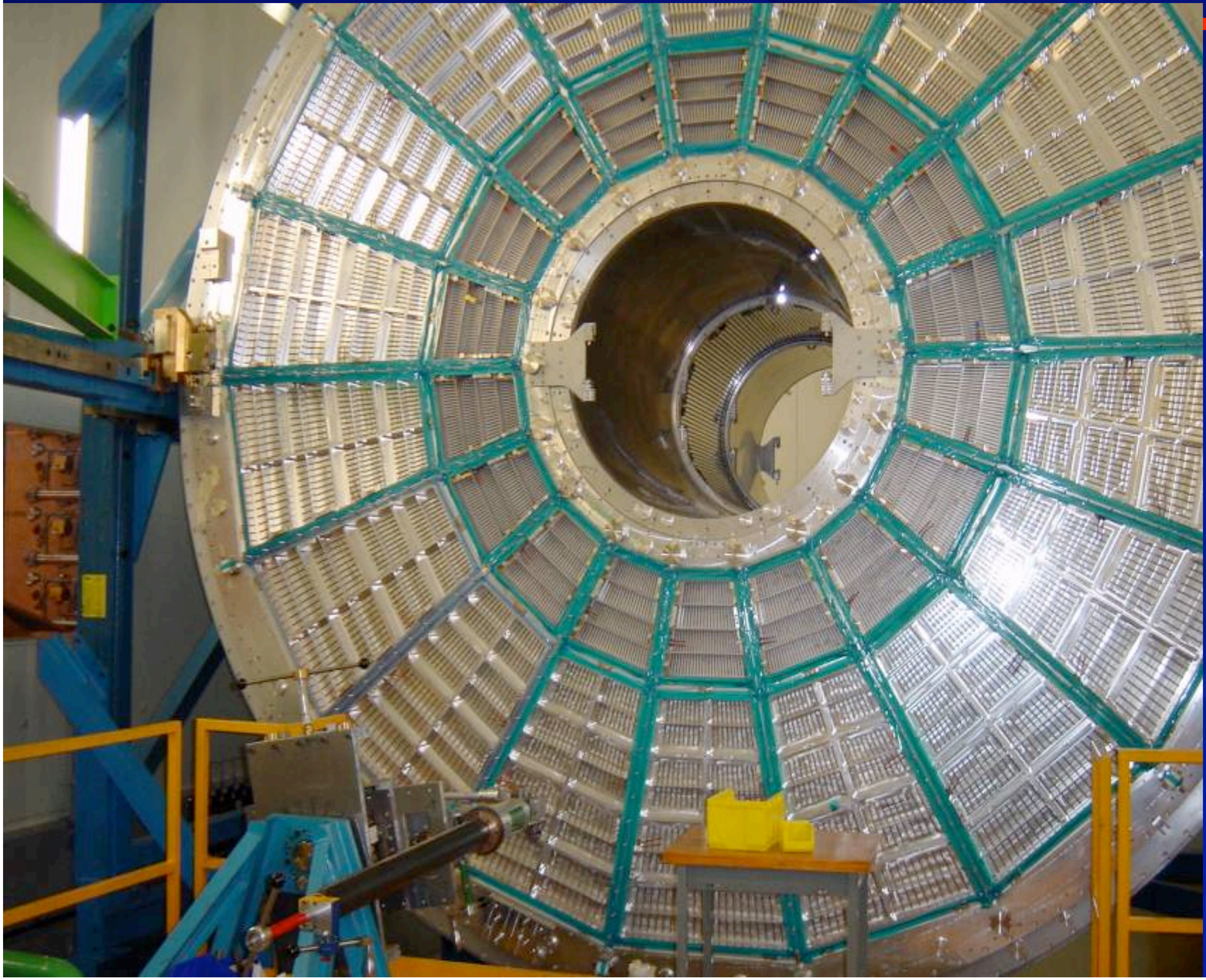
ITS mechanics being assembled



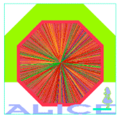




TPC ROC Installation



Milestone dates : Phase 2 to 4



PHASE	Detector	Start	Finish
PHASE 2 - 3	Muon detectors	Jan 2006	End 2006
PHASE 2	HMPID	09.01.2006	07.05.2006
	TOF / TRD	08.03.2006	31.07.2006
	PHOS + services, emcal support frame	01.08.2006	End Aug. 2006
PHASE 3	TPC in parking position	01.09.2006	02.10.2006
	ITS Barrel (SDD,SSD)	03.10.2006	16.10.2006
	Vacuum (central Be chamber)	17.10.2006	16.11.2006
	FMD/V0/T0 (RB26)	17.11.2006	28.11.2006
	Pixel + ITS barrel + service	29.11.2006	12.01.2007
	TPC in final position	13.01.2007	16.02.2007
PHASE 4	FMD/V0/T0 and PMD (RB24)	17.02.2007	02.03.2007
2nd installation window	TOF/TRD/PHOS	03.03.2007	28.03.2007
	Beam line + shielding	29.03.2007	End April 2007

More experiments at LHC

Totem: elastic and total cross section;
hard diffraction (together with CMS)

Moedal: magnetic monopoles

LHCf: very forward production of π^0's, γ's (cf. energy calibration of very hifh energy cosmic rays)

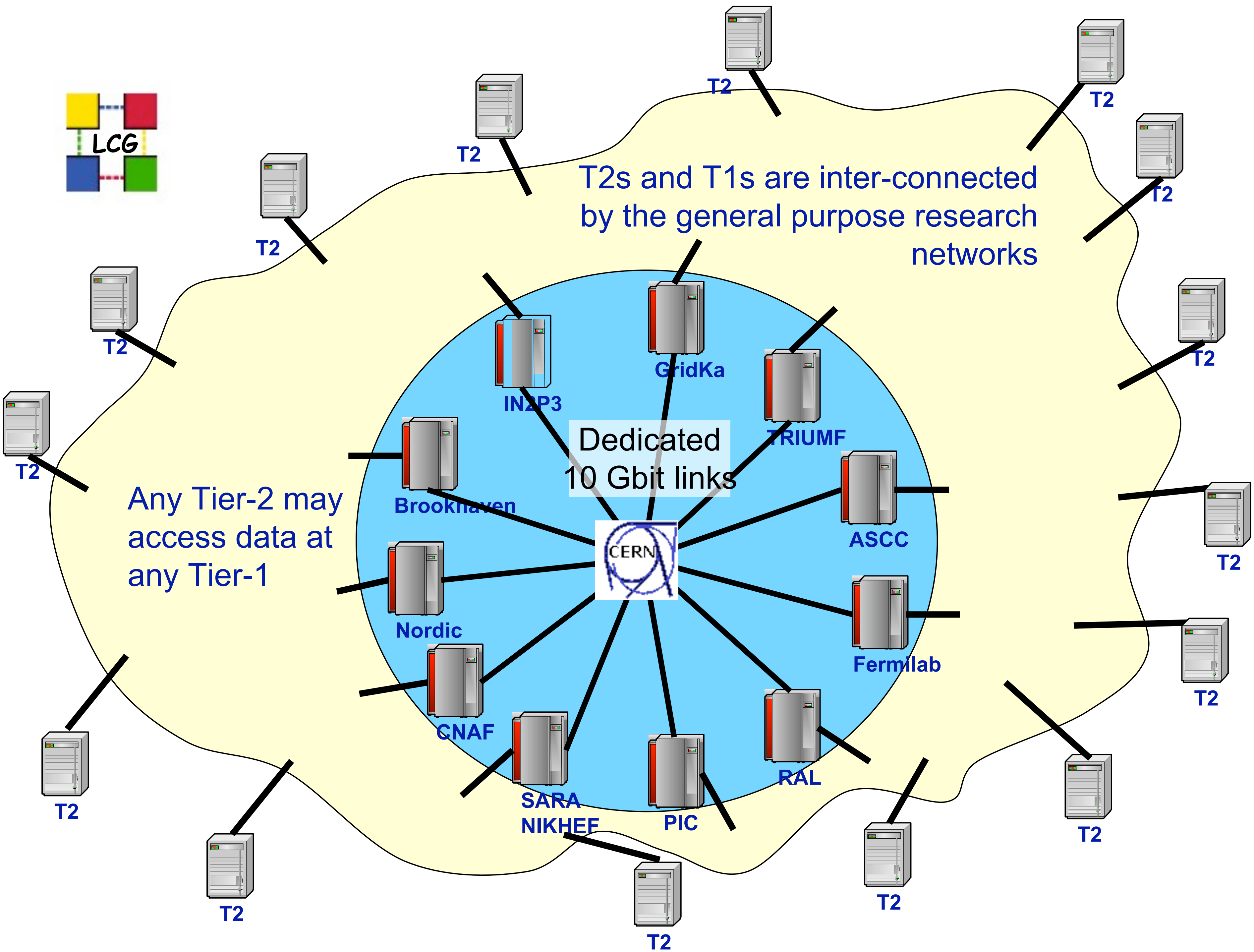
Computing

The LHC Computing Grid: LCG
(Project leader Les Robertson)

is about storing 15 PB (imagine!) of new data per year; processing them and making the information available to thousands of physicists all around the world!

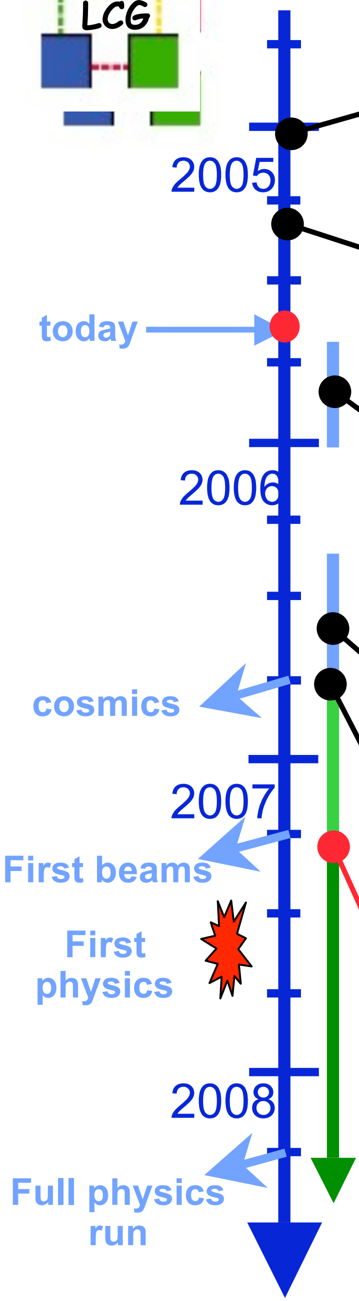
Model: 'Tiered' architecture; 100,000 processors; multi-PB disk, tape capacity

Leading 'computing centers' involved



LCG
T2s and T1s are inter-connected by the general purpose research networks
Any Tier-2 may access data at any Tier-1
Dedicated 10 Gbit links
CERN
IN2P3
GridKa
TRIUMF
Brookhaven
ASCC
Nordic
Fermilab
CNAF
SARA NIKHEF
PIC
RAL
T2

Building the Service



SC1 - *Nov04-Jan05* - data transfer between CERN and three Tier-1s (FNAL, NIKHEF, FZK)

SC2 – *Apr05* - data distribution from CERN to 7 Tier-1s – 600 MB/sec sustained for 10 days (one third of final nominal rate)

SC3 – *Sep-Dec05* - demonstrate reliable basic service – most Tier-1s, some Tier-2s; push up Tier-1 data rates to 150 MB/sec (60 MB/sec to tape)

SC4 – *May-Aug06* - demonstrate full service – all Tier-1s, major Tier-2s; full set of baseline services; data distribution ***and*** recording at nominal LHC rate (1.6 GB/sec)

LHC Service in operation – *Sep06* – over following six months ramp up to full operational capacity & performance

LHC service commissioned – *Apr07*

LCG

- The "Baseline Services" for the LCG services at startup have been agreed. These are the basic services that must be provided at CERN, Tier-1 and Tier-2 centres, and have to be in operation for Service Challenge 4 in April 2006.
- A detailed plan for Service Challenge 3 has been agreed with Tier-1 sites and the experiments. Service Challenge 3 is being prepared now and is scheduled to open as a stable service including 9 Tier-1 centres and several Tier-2s in September 2005.
- The deployment plan for the new CASTOR mass storage management system at CERN has been agreed with the experiments, with the aim of completing the migration of LHC to this system by the end of February 2006.
- The TDR for the initial LHC computing services is complete.

The LCG project is taking an active part in the preparation of the proposal for the second phase of the EGEE project (April 2006-March 2008). This will be an evolution of the current project, with the major emphasis remaining grid operations.

Physics

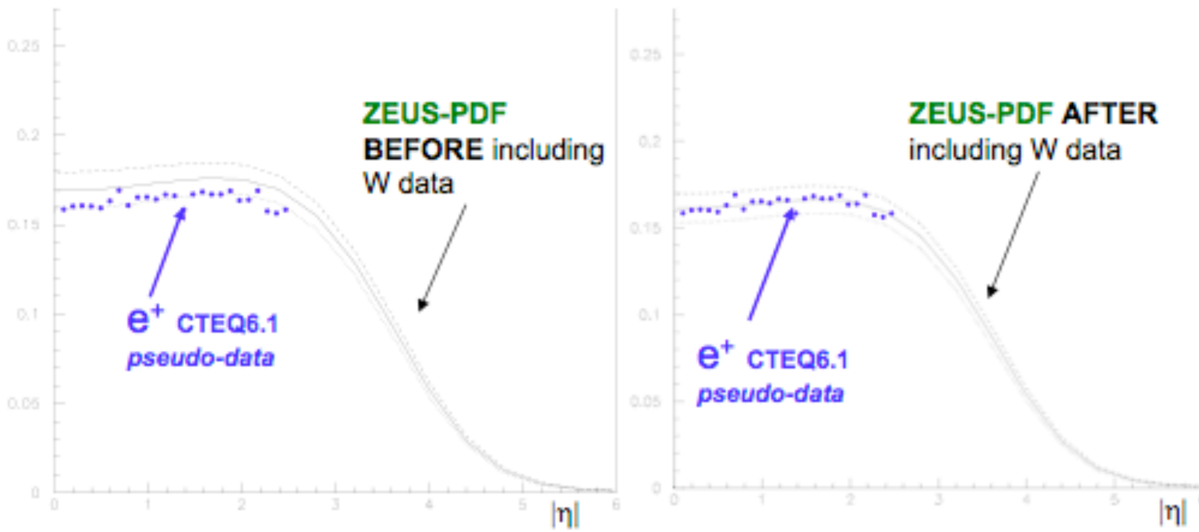
EXAMPLE of initial physics study

Studies of W and Z production

Constraints on Parton Distribution Functions (PDF) from W and Z rapidity distributions

Simulation of realistic experimental conditions for $W \to e\nu$:

• Backgrounds • Systematics on charge misidentification (Rome data)



PDF constraining potential of ATLAS: Include 1M ATLAS pseudo-data (ATLFAST) in ZEUS PDF fit

Impose a 4% uncertinty on data points

Observe 35% error reduction on low-x gluon shape parameter λ $(xg(x) \sim x^{-\lambda})$

EXAMPLE, TOP STUDIES

no b-tagging required, straightfwd analysis

Missing	E_T > 20 GeV
1 lepton	P_T > 20 GeV
4 jets(R=0.4)	P_T > 40 GeV

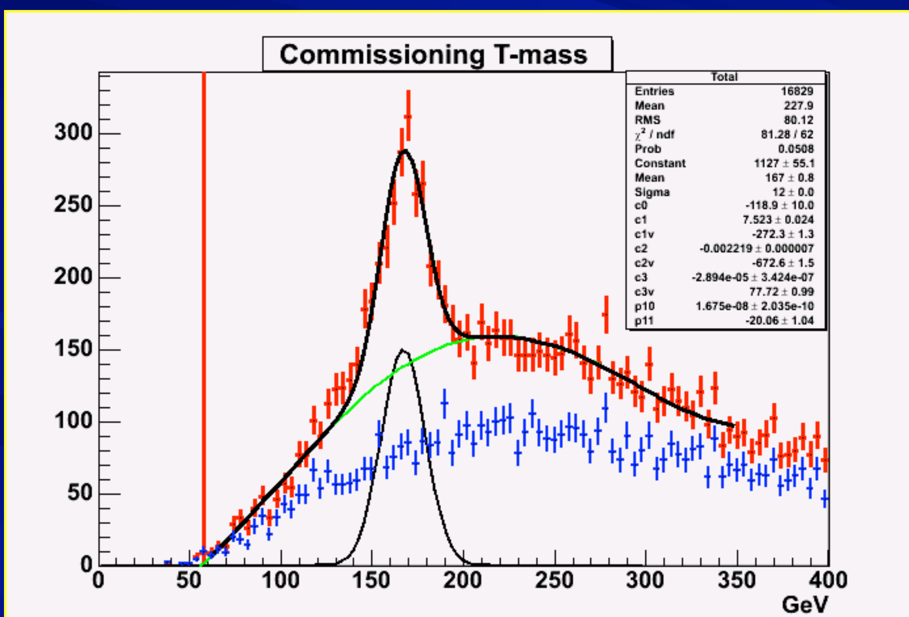
Assign jets to W, top decays

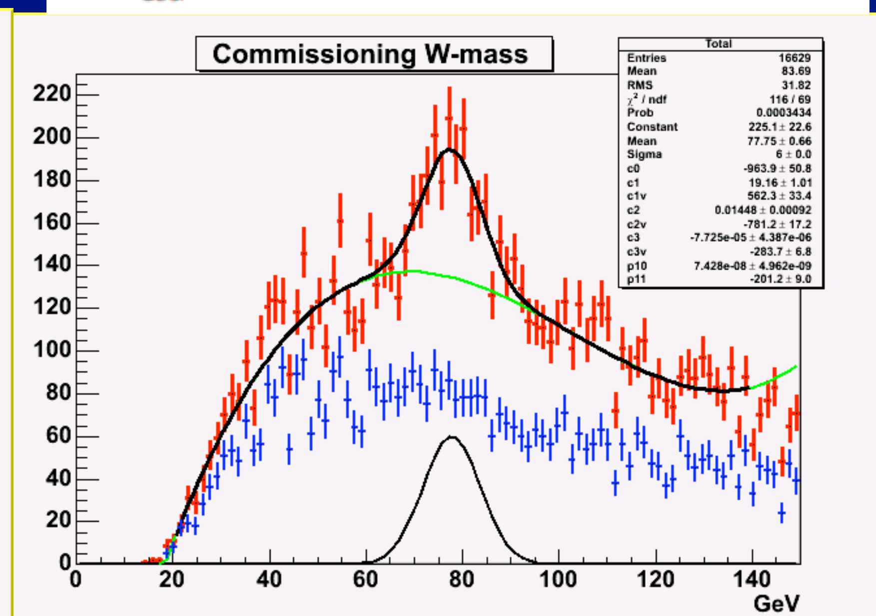
1 Hadronic top:

Three jets with highest vector-sum pT as the decay products of the top

2 W boson:

Two jets in hadronic top with highest momentum in reconstructed jjj C.M. frame.





Which physics the first year(s) ?

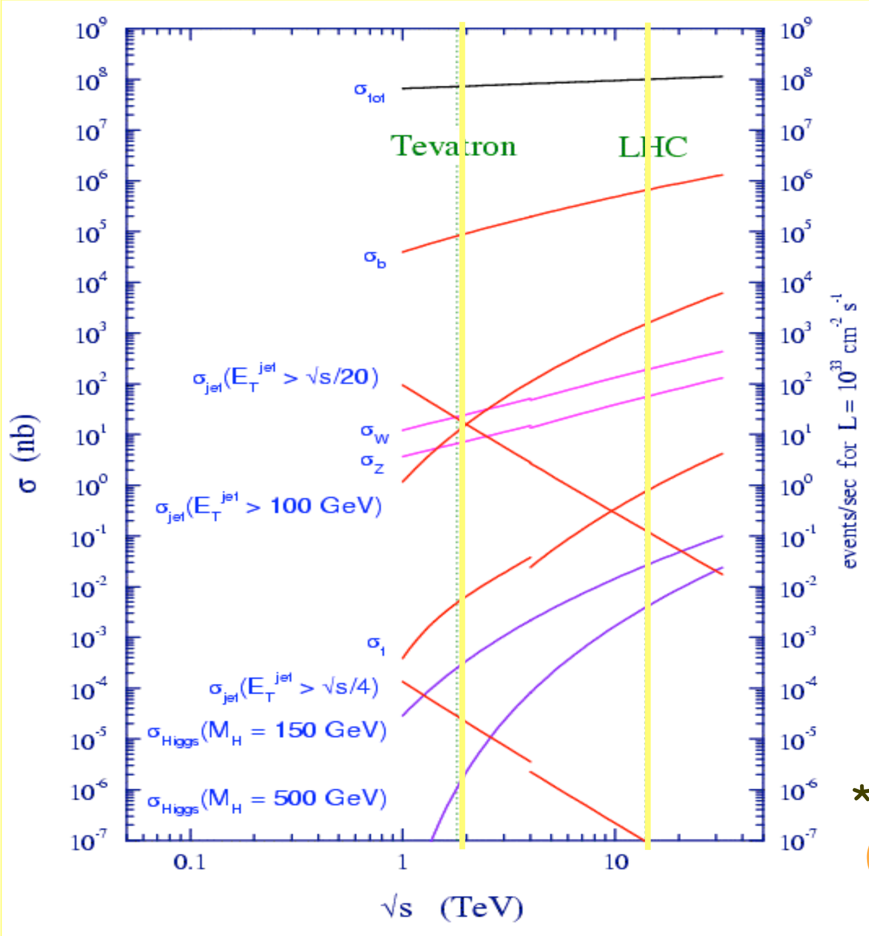
Expected event rates at production in ATLAS or CMS at $L = 10^{33}\ cm^{-2}\ s^{-1}$

Process	Events/s	Events for 10 fb^{-1}	Total statistics collected at previous machines by 2007
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	1.5	10^7	10^7 LEP
t tbar	1	10^7	10^4 Tevatron
b bbar	10^6	$10^{12} - 10^{13}$	10^9 Belle/BaBar
H m=130 GeV	0.02	10^5	?
gluino gluino m= 1 TeV	0.001	10^4	---
Black holes m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3	---

Already in first year, large statistics expected from:

-- known SM processes $\to$ understand detector and physics at $\sqrt{s}$ = 14 TeV

-- several New Physics scenarios



Implications for light Higgs
(assuming the same luminosity/detector/analysis)

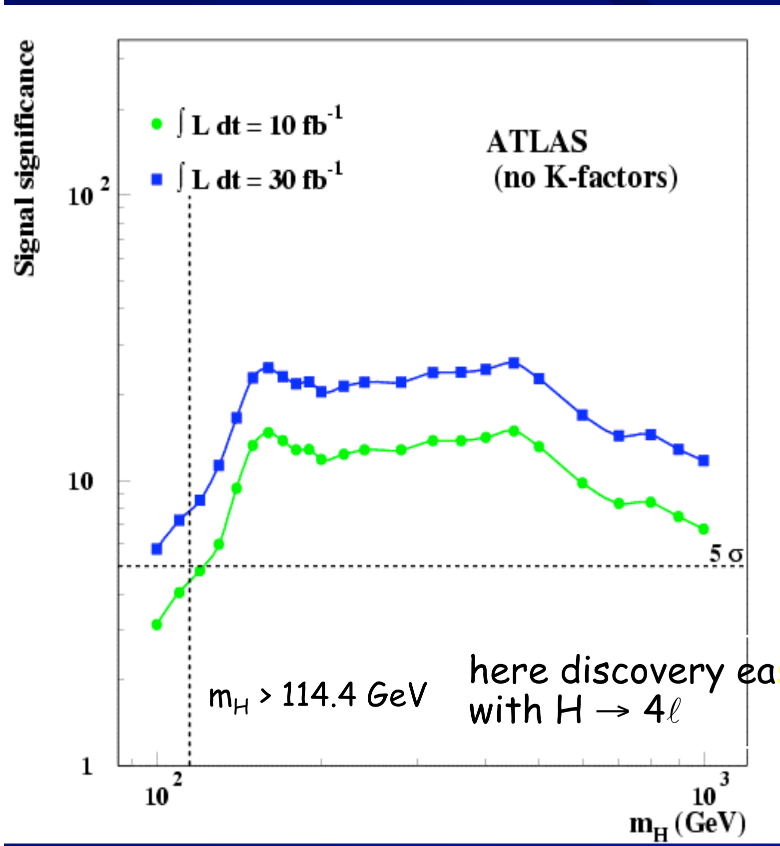
	$qq \to WH \to \ell\nu\, bb$ $qq \to ZH \to \ell\ell\, bb$ m_H=120 GeV	$gg \to H \to WW$ $\to \ell\nu\ \ell\nu$ m_H=160 GeV
S(14)/S(2)	≈ 5*	≈ 30
B(14)/B(2)	≈ 25	≈ 6
S/B(14)/S/B(2)	≈ 0.2	≈ 3
S/√B(14)/ S/√B(2)	≈ 1	≈ 7

*Acceptance ~ 2 times larger at Tevatron
(physics is more central, less initial-state g radiation)

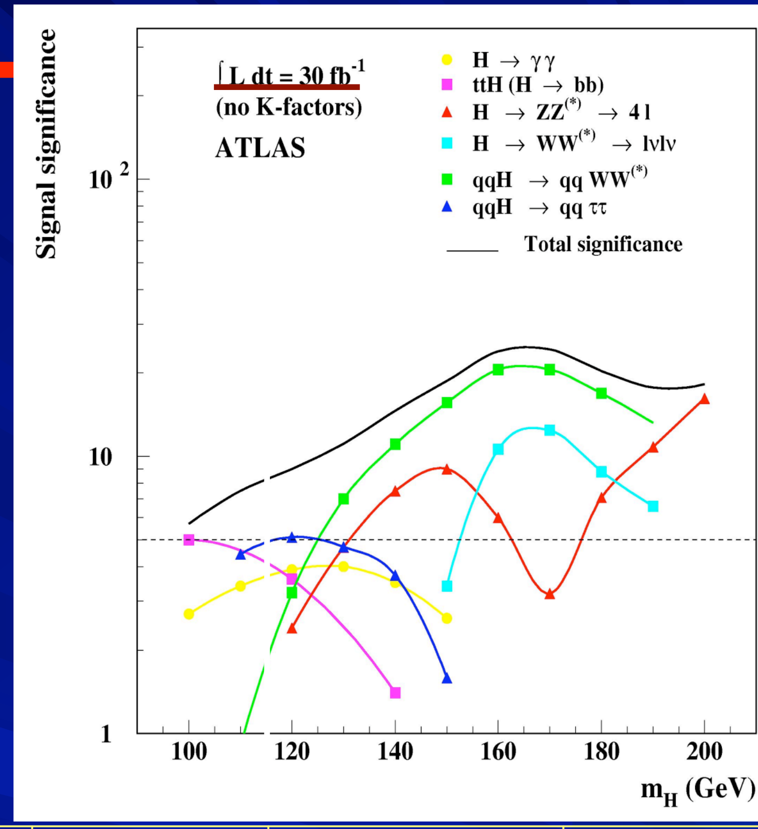
EW cross-sections (e.g. qq→ W, Z, WH) :
LHC/Tevatron ~ 10
QCD cross-sections (e.g. tt, gg→ H) :
LHC/Tevatron ≥ 100 (because of gluon PDF) → cf HERA results

$$\left.\begin{array}{ll} e/jet \sim 10^{-3} & \sqrt{s} = 2 \text{ TeV} \\ e/jet \sim 10^{-5} & \sqrt{s} = 14 \text{ TeV} \end{array}\right\} p_T > 20 \text{ GeV}$$

Standard Model Higgs



here discovery easier with $H \to 4\ell$



$m_H \sim 115$ GeV   10 fb^{-1}

total $S/\sqrt{B} \approx$ [redacted]

ATLAS	$H \to \gamma\gamma$	$ttH \to ttbb$	$qqH \to qq\tau\tau$ ($\ell\ell$ + ℓ-had)
S B	130 4300	15 45	~ 10 ~ 10
$S/\sqrt{B}$	2.0	2.2	~ 2.7

[redacted]

Full GEANT simulation, simple cut-based analyses

Conclusions

The LHC project (machine; detectors; LCG) is well underway for physics in 2007

Detector construction is generally proceeding well, although not without concerns in some cases; an enormous integration/installation effort is ongoing – schedules are tight but are also taken very seriously.

LCG (like machine and detectors at a technological level that defines the new ‘state of the art’) needs to fully develop the functionality required; new ‘paradigm’.

Large potential for exciting physics.